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**Australian Government**  
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# The Impact of Stressors on Military Performance

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DSTO-GD-0780

## **ABSTRACT**

Military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. If we are to gain a better understanding of the impact of the operational environment and operational demands on soldier performance we need to understand the way in which these impact on the soldier. This paper focuses on the impact of stress on military performance. Some key theories and models that describe the stress concept are briefly reviewed. A core feature of the majority of these is the notion of Inputs (environmental demands), Adaptation (responses occurring within a person that enable them to adapt to environmental demands), and Outputs (performance as a consequence of the environmental demands and any adaptations made). This paper identifies confusion surrounding the concept of stress and terminology such as stressor. An overview of selected Inputs is followed by an oversight of the nature of Adaptation. Research related to Outputs is summarised and a brief overview provided of methodological issues. The paper identifies that there are many unknowns with respect to the impact of Inputs on Outputs, and also the Adaptation responses. To better identify means of optimising soldier performance and mitigate against potential negative effects on Inputs, more research is needed. It is particularly important to conduct field studies that consider the interactions of two or more stressors (Inputs).

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## The Impact of Stressors on Military Performance

### Executive Summary

Military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. If we are to gain a better understanding of the impact of the operational environment and operational demands on soldier performance we need to understand the way in which these impact on the soldier.

This document focuses on the impact of stress on military performance. It identifies confusion in the literature surrounding the concept of stress and terminology such as stressor. It provides a working definition of stress, followed by an overview of the nature of modern military operations. This is followed by a summary of some key theories and models that describe the stress concept which are briefly reviewed.

A core feature of the majority of these theories and models is the notion of Inputs (environmental demands), Adaptation (responses occurring within a person that enable them to adapt to environmental demands), and Outputs (performance as a consequence of the environmental demands and any adaptations made). This review identifies that we still have a limited understanding of the impact of stress on performance. This is largely due to (1) uncertainty with respect to cognitive resources; (2) immaturity of our understanding of mechanisms involved in evaluating the nature of a perceived threat; (3) few studies investigate changes in the environment and cognitive state over time; and (4) our understanding of the impact of Inputs (stressors) on cognitive performance is limited, as is our understanding of the interaction of various Inputs.

Selected Inputs of relevance to the military environment are defined, followed by a review of Adaptation responses. This is followed by a review of some of the research related to Outputs associated with the specific Inputs focused on in this paper. It is concluded that there is still a lot of uncertainty with respect to the impact of these Inputs on Outputs and further research is needed to gain a better understanding of such impacts. This is particularly important if we want to develop means of mitigating against potentially harmful effects of one or more Inputs. If we can identify appropriate mitigation strategies to optimise soldier performance, as these are likely to alleviate perceived psychological and/or physical strain on a soldier, such strategies are also likely to improve soldiers' well-being.

The operator functional state and how this impacts on their capacity to perform military tasks in extreme environments needs to be considered when evaluating the impacts of Inputs on performance. The following recommendations are made:

1. It is recommended that the Process Model of Stress and Performance (Hancock et al., 2001) be used to underpin research investigating the impact of stress on

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performance. This will allow continuous development and refinement of this model.

2. It is recommended that evaluation of the operator functional state consider the cumulative impact of environmental and task demands on human resource capacity i.e., the operator functional state. This includes consideration of physical and cognitive factors. It is important to identify the combined effect of stressors as physical and cognitive demands draw on overlapping physiological resources.
3. It is recommended that further research is undertaken to identify innate markers of resilience. Identifying personnel who will be least affected by adverse environments may improve performance, reduce training failure rates, and reduce medical costs associated with trauma.
4. It is recommended that research is extended in the area of adaptive automation. This will enable us to provide guidance on appropriate levels of automation, the timing and nature of information to be displayed, assessment of the operator functional state etc. Identification of the operator functional state will enable intervention prior to errors occurring; appropriate adaptive automation will facilitate humans and technology seamlessly sharing control of tasks.

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## Acronyms

ADF	Australian Defence Force
ARL	Army Research Laboratory
CBA	Combat Body Armour
CBRN	Combat, Biological, Radiation and Nuclear protection
COCOM	Contextual Control Model
ConOPS	Continuous Operations
DPCU	Disruptive Pattern Combat Uniform
DSTO	Defence Science and Technology Organisation
ER&D	Enabling Research and Development
HPPD	Human Performance and Protection Division
HRED	Human Research and Engineering Directorate
ISO	International Standards Organisation
LOD	Land Operations Division
MilHOP	Military Health Outcomes Program
NREM	Non-Rapid Eye Movement
OOTW	Operations Other Than War
PTSD	Post-Traumatic Stress Disorder
REM	Rapid Eye Movement
SERE	Survival Evasion, Resistance and Escape
SUSOPS	Sustained Operations
TTP's	Tactics, Techniques and Procedures
UCF	University of Central Florida
WBGT	Wet Bulb Globe Temperature,
WBV	Whole Body Vibration

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# 1. Introduction

By the nature of their task, military forces have always been exposed to stressful situations that the majority of the public fortunately do not have to face. For example, most of us do not have to work in uncomfortable and unhygienic living conditions with their associated diseases, or see acts resulting from man's inhumanity to man. Modern warfare not only sees military personnel facing these "traditional" challenges but also dealing with increased uncertainty and complexity. Operations increasingly involve asymmetric warfare in which the enemy is no longer obvious and behaves in unpredictable ways to compensate for a lack of technological superiority. The face of war has also changed with personnel now predominately involved in operations other than war (OOTW), such as those of a domestic, peacekeeping, peace enforcement and humanitarian nature (Garbutt, 2006; Hancock & Krueger, 2010; Richards, Hodson, Wright, Churchill & Blain, 2003). Irrespective of the nature of the operation and environment within which it occurs, military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. The importance of the impact of stress on the wellbeing of military personnel is recognised by defence organisations internationally, with stress training increasingly forming part of their standard training. In recognition of the potential consequences of exposure to acute stress, the impact of deployment on the health of Australian Defence Force (ADF) members is an area of investigation by the Centre for Military and Veterans' Health under their Military Health Outcomes Program (MilHOP, 2009).

This paper focuses on the impact of stress on military performance. A working definition of stress is followed by a brief overview of the nature of military operations. Some key theories and models that describe the stress concept and attempt to identify mechanisms underlying the response to stress are then briefly reviewed. These theories and models were chosen because of their general acceptance within the stress literature; they are complementary and/or can be integrated, and may provide a framework for evaluating the impact of stress on soldier performance. A core feature of the majority of these theories and models is the notion of Inputs (environmental demands), Adaptation (responses occurring within a person that enable them to adapt to environmental demands), and Outputs (performance as a consequence of the environmental demands and any adaptations made). An overview of potential Inputs is followed by an oversight of the nature of adaptability and some of the methods used to maximise this. A summary of research related to Outputs (performance as a consequence of the Inputs), is followed by an overview of methodological issues. This is followed by an overall summary identifying that there is still a lot of uncertainty with respect to the impact of the selected Inputs on Outputs. These uncertainties need to be addressed if we are to more fully understand the impact of stress on soldier performance, and identify means to mitigate against the impact of Inputs to optimise performance.

## 2. Definition of Stress

Although its use is ubiquitous, there is no singular widely accepted definition of stress. This is largely due to the divergence of concepts in the literature surrounding this concept, with the term “stress” being used to refer to both the cause and effect of discomfort (e.g., Hancock & Szalma, 2006; Kavanagh, 2005; Krueger, 2008; Staal, 2004). This ambiguity is compounded by the different paradigms and experimental procedures used by the different disciplines undertaking research related to stress (Le Fevre, Matheny & Kolt, 2003). Nonetheless, one could argue that this uncertainty reflects an incomplete understanding of research in the area of stress and its associated terminology. Interest in the field of stress began with Selye’s (1936) development of a model of stress, the General Adaptation Syndrome to explain the response to stress. Selye’s model extended the work of Cannon (1932, in Seamon & Kenrick, 1992) who proposed a mechanism by which humans maintained homeostasis, the maintenance of key physiological states within a small range (e.g., temperature, pH, oxygen levels) for effective functioning (Feder, Charney & Collins, 2011; Kopin, 1995). Cannon used the physics terms of “stress” to refer to a force that exerted pressure on the body and disturbed the homeostatic state, and “strain” to refer to the disruption of homeostasis as a result of the stress (Kopin, 1995). When he produced his paper explaining the General Adaptation Syndrome, Selye reversed the meanings of stress and strain due to his poor understanding of English. To obviate confusion, Selye used the term “stressor” to refer to an event that disturbed the homeostatic state of the body, and “stress” to refer to the pattern of responses occurring as a result of the loss of homeostasis. Thus, the biological concepts stressor and stress are equivalent to the physics concepts of stress and strain, respectively (Kopin, 1995).

This paper uses the term stressor to refer to an environmental stimulus (external or internal to the system) that disturbs a person’s homeostatic state. Strain refers to the imbalance within the human as a result of the stressor. Stress refers to the composite of stressor, strain, and compensatory responses consciously or unconsciously made by a person in order to reduce the strain experienced as a result of one or more stressors. Given the aforementioned distinction between stressor and strain, when looking at the impact of stress on performance one is really looking at how the human’s behaviour changes in order to restore homeostasis. Simply put, stressors are *inputs* to the system that disrupt homeostasis, thereby straining the system. This strain invokes *adaptation* processes aimed at restoring equilibrium. The impact of the input and adaptations can be seen in changes to performance – the *output*.

## 3. Overview of the Nature of Military Land Operations

Although combat situations are arguably the most stressful for the soldier (Bartone, 2006; Lieberman, Caruso, Niro & Bathalon, 2006; Russo, Fiedler, Thomas, & McGhee, 2005), modern operations involve additional stressors (Bartone, 2006). Not only is this due to the fact personnel are deploying more frequently due to the increased demands on limited manpower, but also the fact that personnel are increasingly involved in operations other

than war (OOTW), such as those of a domestic, peacekeeping, peace enforcement and humanitarian nature (Garbutt, 2006; Hancock & Krueger, 2010; Richards, et al., 2003). Each of these operations places different demands on the soldier and requires different skill sets. The different skills required in missions of a peacekeeping and humanitarian nature was recognised by the Australian Defence Force (ADF) with the establishment of the ADF Peace Operations Training Centre in 1993. This centre provides specific training for personnel being deployed on peacekeeping missions. However, modern operations often see personnel engaged in what is commonly called the “3 block war”, whereby they can be engaged in a diverse range of missions within a short space of time and space (Killion, Bury, de Pontbriand & Belanich, 2009). Specifically, personnel are likely to fulfil peacekeeper, humanitarian aid assistance and warfighting roles within overlapping spatiotemporal dimensions (Dorn & Varey, 2009). As well as being exposed to a range of external stressors (e.g., climate, blast, load carriage) this rapid change of role, mission objectives and, potentially, rules of engagement, introduces additional stressors. Soldiers have to rapidly change their perspective on their environment, civilians within it, and the ways in which they are allowed to interact and respond to perceived threats. When a soldier is primarily trained for warfighting, and/or the bulk of their time whilst on operations has been spent fulfilling warfighting duties, the sudden change to providing humanitarian assistance with potentially different rules of engagement is likely to result in cognitive dissonance and increase the stress already present due to the urban environment. Cognitive dissonance is a well recognised construct within the psychological literature and refers to the discomfort a person feels when they act in a way that contradicts their established values and attitudes. When a soldier is primarily trained for warfighting, based on findings from World War II, Evans (2007) argues that the multidimensional nature of urban warfare makes it mentally and physically taxing. Personnel experience sensory overload due to the ongoing noise, vibrations and risk of being injured as a consequence of weapons being used in confined areas. They also experience psychological stress related to the likelihood of being ambushed or otherwise attacked, and of inadvertently killing or injuring non combatants.

Recent campaigns increasingly involve soldiers in urban warfare where the enemy is difficult to discern and attack because of the civilian population, as well as asymmetric warfare with the enemy using unconventional tactics and methods. The additional burdens imposed by increased uncertainty as to the opponents’ actions and whereabouts, and increased battle space complexity, are compounded by modern technology (Killion et al, 2009; Wesensten, Belenky, & Balkin, 2005). For example, in a networked environment the modern soldier has access to a large amount of information which can overwhelm them and have a detrimental effect on performance (Barnett, 1999; Eppler & Mangis, 2004). Not only is the soldier exposed to a large amount of information but they also have to bear the additional weight of technologies providing this information, despite the fact that heavy loads are identified as potential stressors that can result in fatigue or injury (Krueger, 2008). Despite Defence organisations’ realisation of the need to reduce soldiers’ load carriage, there is a growing trend to provide soldiers with new technologies aimed at improving their performance (e.g., information technology, improved weapon systems) as well as enhanced protective clothing. Although the additional weight imposed by any one component may be small, the collective weights combine to increase the weight borne by a soldier, which conflicts with the goal of reducing the load burden. The increases in

uncertainty, complexity, information, and load carriage arguably mean the modern soldier operates in a more stressful environment than their historic counterpart. Military personnel need to be multiskilled, effectively utilise new technologies, and rapidly adjust to new missions within short time frames (Killion et al., 2009).

Irrespective of the nature of the operation and environment within which it occurs, military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. These can be broadly grouped into physical and psychological stressors (Wilson, Braithwaite, & Murphy, 2003).

Physical stressors include: noise (Orasnu & Backer, 1996; Salas, Driskell, & Hughes, 1996; Wilson et al., 2003, climate (Killion et al., 2009; Orasnu & Backer, 1996; Krueger, 2008; Wilson et al., 2003), sleep deprivation and/or fatigue (Killion et al., 2009; Krueger, 2008; Orasnu & Backer, 1996; Wilson et al., 2003), lack of nutritious food (Wilson et al., 2003), other environmental characteristics such as insects, terrain, altitude etc. (Wilson et al., 2003), and vibration (Krueger, 2008).

Psychological stressors include: isolation (Bartone, 2006; Killion et al., 2009), sense of danger and/or threat, (Bartone, 2006; Krueger, 2008; Orasnu & Backer, 1996), ambiguity (Bartone, 2006, Wilson et al., 2003), perceived loss of control (Bartone, 2006, Wilson et al., 2003), boredom (Bartone, 2006), and workload (Bartone, 2006, Killion et al., 2009; Orasnu & Backer, 1996, Wilson et al., 2003).

Although the impact of these stressors can be studied in isolation in a laboratory setting, it is very difficult to disentangle the effect of an individual stressor on soldier performance during military operations (Killion et al., 2009). Soldiers are exposed to combat stress, which is “the complex and constantly changing result of all the stressors and stress processes inside the soldier as he performs the combat-related mission. At any given time, in each soldier, stress is the result of the complex interaction of many mental and physical stressors” (FM 22-51, Headquarters, Department of the Army, 1994). The combat stress reactions are natural responses to factors related to the operational environment (e.g., separation from family, noise, fatigue, sleep deprivation, heat etc.) and should not be confused with clinical manifestations such as post-traumatic stress disorder (PTSD) or acute stress disorder. Because of the potential impact of stress on performance, defence organisations internationally are looking at ways to recognise combat stress reactions as well as mitigating their effects on performance. Reactions themselves may vary in their severity and the US Department of the Army Field Manual 6-22-5 identifies symptoms that commanders and personnel should watch out for. Mild reactions may result in behavioural changes that are noticeable only to the person themselves or close friends (FM 6-22-5, Headquarters, Department of the Army, 2000). Severe stress reactions may impact on performance and/or cause concern about the personal safety of the person and/or those around them (FM 6-22-5, Headquarters, Department of the Army, 2000). Before defining key stressors, the next section provides an overview of theories and models of stress so as to identify a framework for future research on the impact of stress on performance.

## 4. Brief Overview of Stress Theories

There are several recent, comprehensive literature reviews, some of which summarise research and theory related to stress and performance (e.g., Byrt & Mouzakis, 2007; Hancock & Szalma, 2008; Kavanagh, 2005; Staal, 2004), whereas others provide a more general overview of the nature of stressors soldiers may be exposed to, what a commander needs to be aware of with respect to soldiers' reactions to stressors, and measures to mitigate these, such as training practices (e.g., Kearny, Creamer, Goynes & Marshall, 2004; Murphy & Fogarty, 2009). As excellent reviews of the stress phenomenon are in existence (the interested reader is referred to e.g., Driskell & Salas, 1996; Hancock & Szalma, 2008; Hancock & Desmond, 2001; Killian et al., 2009), this paper does not present a comprehensive review of the stress phenomenon and all the competing theories. Rather, it provides a brief overview of theories that accord with the concept of "inputs", "adaptation", and "outputs". Inputs can be adverse or beneficial, respectively resulting in a person being in a state of distress (the Input is a negative event or emotion) or eustress (the Input is a positive event or emotion). The general premise of all theories is that performance degrades as a result of exposure to one or more stressors. This is seen as a non-linear relationship, with hypostress (too little strain) being just as detrimental to performance as hyperstress (too much strain). Although eustress is generally regarded as beneficial, performance degradation as a result of too little or too much strain can occur irrespective of whether the inputs are perceived as being adverse or beneficial to the person.

### 4.1 General Adaptation Syndrome

Selye (1936) found that many agents (e.g., toxins, bacteria, heat, cold, trauma) induced a similar physiological reaction within people: an alarm reaction, a stage of resistance, and a stage of exhaustion. Because this indicated the body was coming under strain, Selye used the term "stress" (derived from the Latin word "stringere" meaning to pull tight) to describe this pattern of response to an adverse event. As the physiological reaction allowed the body to adapt to the strain imposed by stressors and thus regain a state of balance within the body, Selye named this phenomenon the General Adaptation Syndrome (see Figure 4.1.1). Any encounter with a stressor increases activation of the sympathetic nervous system, which is responsible for the well-known "fight or flight" response. Basically, this prepares the body for staying and fighting a threat or fleeing from it. This activation interferes with homeostasis and causes strain on the body. The resistance stage allows the body to adapt to this strain and therefore regain equilibrium. However, under prolonged exposure to a stressor or exposure to concurrent stressors, the body is unable to maintain the effort required for resisting the strain and maintaining homeostasis and therefore enters a stage of exhaustion.

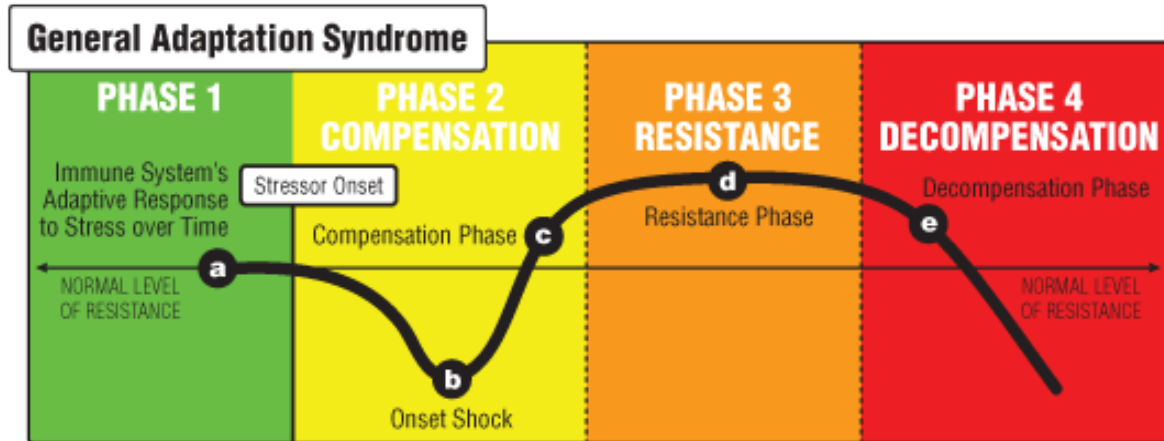


Figure 4.1.1: Selye's General Adaptation Syndrome

(Source: [https://www.campustoolkit.com/textbooks/general\\_adaptation\\_syndrome.php](https://www.campustoolkit.com/textbooks/general_adaptation_syndrome.php))

Selye further noted that the General Adaptation Syndrome occurred irrespective of whether the stressor was a positive or negative event or emotion. He therefore used the terms "eustress" and "distress" to refer respectively to the physiological response to positive events or emotions, and negative events or emotions. Selye (1987, cited in Cooper & Dewe, 2004) further identified two types of distress: hypostress (understress) and hyperstress (overstress). He further argued (1979, cited in Cooper & Dewe, 2004) that eustress improves performance and reflects a state of homeostasis.

## 4.2 Yerkes-Dodson Inverted-U Curve

Selye's (1936) General Adaptation Syndrome accords well with the Yerkes-Dodson Law (1908, cited in Zimbardo, 1992) that argues there is an optimal level of arousal for performance, where arousal reflects the physiological state of the person (see Figure 4.2.1).

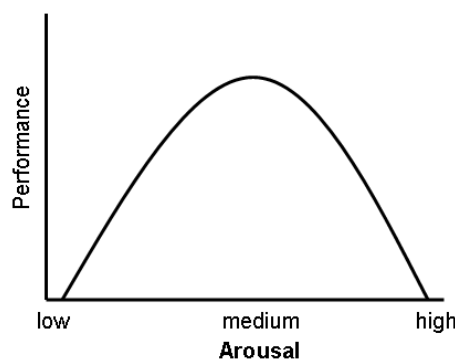


Figure 4.2.1: The Yerkes-Dodson Law

Source: <http://images.wikia.com/psychology/images/6/61/YerkesDodsonLawGraph.png>

Although focusing on the impact of arousal on performance, the Yerkes-Dodson Law has been used to explain the impact of stress on performance, based on the assumption that a

disruption in homeostasis will create changes in a person's arousal levels. Research has also shown that the optimal level of arousal depends on the nature of a task. A moderate to high level of arousal results in optimal performance of simple or well-practiced tasks whereas novel or complex tasks are best performed at low-moderate levels of arousal (see Figure 4.2.1).

The Yerkes-Dodson Law has been influential; however it ignores psychological factors and is specifically a model explaining the impact of arousal on performance. Selye's argument that a person's interpretation of a stimulus and how they decide to respond to it determines whether it creates eustress or distress (1987, cited in Le Fevre, Matheny & Kolt, 2003), concurs with the view of Cox and McKay (1976, cited in Cox, 1988) that a person's response to a stressor is not simply physiological. Rather, the amount of strain induced by a stressor depends on a person's perception of their ability to cope with that stressor. Moreover, they argue that boredom is also stressful. Their theory combines terminology and concepts of the General Adaptation Syndrome and the Yerkes-Dodson Law to include the role of cognition and, although the principles are similar to those of the Yerkes-Dodson Law, Cox and McKay specifically link stress to performance. The inverted U-curve often used to reflect their theory is very similar to those of the General Adaptation Syndrome and the Yerkes-Dodson Law (see Figure 4.2.2). They argue boredom results in low arousal and low performance, the physiological response related to eustress elicits moderate arousal and optimal performance, and the state of distress elicits high arousal and low performance. Boredom can be seen as similar to Selye's concept of hypostress.

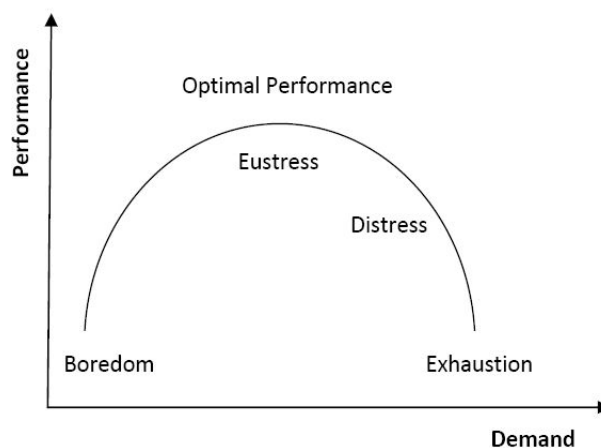


Figure 4.2.2: The Human Performance Curve of Cox and McKay (1976).

Source: [http://wikieducator.org/File:Human\\_Performance\\_Curve.jpg](http://wikieducator.org/File:Human_Performance_Curve.jpg)

### 4.3 Maximal Adaptability Model

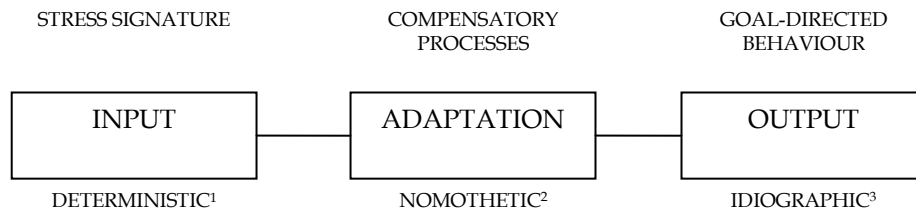


Figure 4.3.1: A three-part differentiation of the concept of stress

Source: Hancock and Szalma (2008)

<sup>1</sup>Deterministic: caused by an event

<sup>2</sup>Nomothetic: rule based

<sup>3</sup>Idiographic: person specific

Hancock and Warm (1989, cited in Hancock & Szalma, 2008) developed the Maximal Adaptability Model to allow prediction of the impact of stress on performance. This model identified three key aspects of stress which they termed the “trinity of stress”: Input, Adaptation, and Output (see Figure 4.3.1). Input is seen as a stress signature reflecting the real-world environment and its combination of potential stressors. Adaptation includes compensatory processes invoked in response to the input and aimed at restoring a state of homeostasis. Although people may not all have the same compensatory mechanisms, the mechanisms themselves work the same way in everyone. Hancock and Warm therefore regard these as being nomothetic (applying basic rules). Output is the final component in the Maximal Adaptability Model and refers to a person’s response to the stressor with respect to their goals. As the goals and cognitive state are person specific, Hancock and Warm regard output to be idiographic. Although similar to Selye’s (1936) General Adaptation Syndrome, Hancock and Warm’s model considers the role of both physiological responses and psychological appraisal in the adaptation process, and focuses on the impact of stressors on performance, rather than the physiological system.

A central feature of the Maximal Adaptability Model is that people generally manage to adapt to stressors without major performance degradation. Unlike the Yerkes-Dodson Law and the Human Performance Curve of Cox and McKay (1976, cited in Cox, 1988) that suggest that there is an optimal arousal level for performance after which time it deteriorates, Hancock and Warm (1989, cited in Szalma & Hancock, 2008) believe people adapt well to either high or low levels of stress, such that output is maintained at a stable plateau. They represent this as an extended-U curve (see Figure 4.3.2).

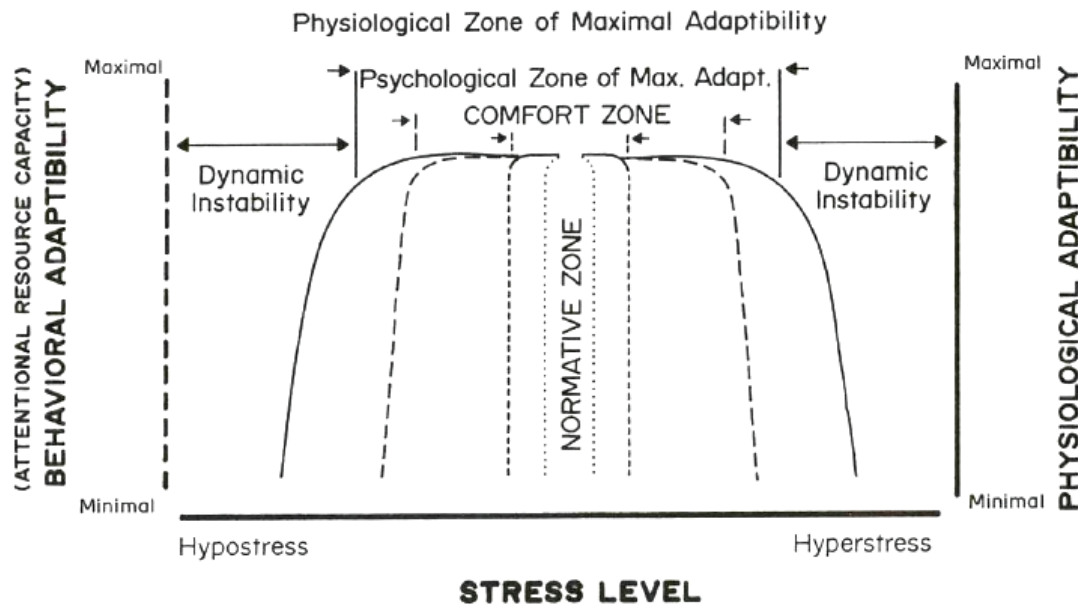


Figure 4.3.2: Hancock and Warm's (1989) Extended-U concept of stress and response capacity.

Source: Hancock and Szalma (2008).

The extended U-curve model indicates that people have a comfort zone, a psychological adaptation zone, and a physiological adaptation zone. The normative zone represents the stress level at which a person achieves optimal performance. Humans can tolerate some departure from the normative zone whereby performance remains satisfactory without the need for physiological or psychological adaptation. This is represented in the model by the comfort zone. Beyond this, psychological or physiological adaptations are necessary if performance is to be maintained. However, if a person is exposed to too few or too many stressors this affects their ability to adapt such that there is a loss of comfort as well as a decrease in their capacity for physiological adjustment or behavioural response.

Essentially, performance deteriorates under situations of hypostress and hyperstress. There is a stable response plateau within these two extreme arousal states. As people approach the states of hypostress or hyperstress their performance starts to deteriorate rapidly until it reaches a point of extreme failure. Hancock and Warm (1989) also identify that the task itself is a cause of stress. Moreover they regard stress inputs as being multidimensional as they exist in time and space. The spatial dimension considers the spatial organization of the task (e.g., the location of a target) as well as demands made on cognitive resources such as working memory, attention, decision-making and response capacity. The temporal dimension reflects the amount and speed of information the person is exposed to. Hancock and Warm's identification of the important role cognition plays in perception of whether a stressor is beneficial or adverse, the ability of stressors to impact on cognitive resources, and recognition of the disruptive nature of hypostress and hyperstress are all consistent with Selye's General Adaptability Syndrome.

#### 4.4 Compensatory Control Model

Although the Maximum Adaptability Model extends the General Adaptation Syndrome by identifying that people adapt well to stress with behaviour reaching a stable plateau, it does not explain the mechanisms by which this occurs. Despite the fact people are exposed to what should be a stressful situation, it is often difficult to identify the impact of stress on their performance. This is because physiological and/or psychological adaptations have occurred to compensate for the strain evoked by the stressor. Kahneman (1971, cited in Sanders, 1971) attributed this to attentional mechanisms that maintain our focus on the task at hand. However, this compensatory activity has a cost to the human system and also impacts on other tasks. Humans may become more labile, ignore low priority tasks, and the autonomic-endocrine system may be compromised (Hockey, 1993).

Hockey (1993) argues that the failure to observe performance decrements due to stress does not mean that a person is not being affected by stress. Rather, he sees the effort to maintain homeostasis within the body resulting in affective or psychophysiological changes. Hockey further identifies four major ways in which stress impacts on performance:

**Decrement on the primary task.** This is rarely seen in laboratory or field research. However, Hockey states that when studies have used tasks requiring extended concentration and involving unpredictable events (e.g., vigilance tasks) they have found stressors increased both response time and error rates. This is because the concerted effort interferes with the body's compensatory control mechanisms.

**Compensatory costs.** As Hockey identifies, stress research has demonstrated that when a person's performance on a primary task is unimpaired, this is compensated for by an increase in activation of the sympathetic nervous system (e.g. increased production of catecholamines), subjective perception of increased effort, and/or a subjective feeling of strain (i.e. a feeling that they are under stress). Conversely, where performance is impaired research has found no evidence of compensatory responses. This indicates that there is a trade-off between primary task performance and control effort. That is, the more effort required to maintain task performance the greater the subjective feeling of strain and/or sympathetic nervous system activation. However, if task performance is allowed to deteriorate, the less a person feels under strain, reflected in absence of sympathetic nervous system activation. Hockey identifies that few studies investigate the compensatory control mechanisms when looking at the impact of stressors on performance.

**Strategic Adjustment.** Hockey also notes evidence showing people change the way they approach a task in order to maintain performance. One example of this is the common phenomenon of narrowing of attention whereby a person focuses on a particular task and becomes unaware of events unrelated to this task. Other examples of strategic adjustment include adoption of rigid serial processing as opposed to flexible parallel processing by aircraft controllers when faced with a large number of aircraft. The bottom line here is people have been shown to adopt less effortful strategies and/or reduce the load on working memory.

**Fatigue after-effects of sustained work.** Hockey identifies that sometimes the impact of sustained work effort and/or sustained exposure to a stressor is only observed after the event. This is evidenced by people expending less effort on other tasks once the demanding event is over. Alternately, if a stressor has impacted on performance, performance degradation may continue even when the stressor is removed.

Hockey and colleagues have developed a cognitive-energetic model to explain the effects of stress on performance and how energy is allocated in order to meet task objectives (see Hockey, 1997). Similar to the General Adaptation Syndrome (Selye, 1936) and the Maximal Adaptability Model (Hancock & Warm, 1989), Hockey's Compensatory Control Model conceptualises stress as reflecting a disruption in homeostasis as a result of perceived stressors and then defines how the impact of stress is regulated. Basically, performance is maintained through comparison of response outcomes with the desired goal and/or required standards (Hockey, 1993, 1997). Performance levels can be impaired by increases of external pressure (e.g., increased task demands, environmental stressors such as noise, heat etc.) or a decrease in internal resources necessary to complete the task (e.g., as a result of fatigue, cognitive overload, illness etc).

Similar to the Maximal Adaptability Model (Hancock & Warm, 1989), the Compensatory Control Model has the central premise that people adapt to stressful environments or situations where they are over-worked or under-worked. The model assumes that behaviour is goal-directed, goal states are governed by self-regulatory processes, and maintenance of homeostasis uses resources (i.e., has energetic costs) (Hancock & Szalma, 2008; Hockey, 1993, 1997).

The Compensatory Control Model (see Figure 4.4.1) consists of two levels of control: A lower-level automatic regulation of performance (e.g., for well practiced tasks or those involving established skills) and an upper-level that strategically allocates resources through controlled processing. The lower level places a low demand on energetic resources whereas the upper level involves effortful processing (Hancock & Szalma, 2008; Hockey, 1993, 1997).

A central assumption of the Compensatory Control Model is that overt performance is a consequence of internal states, with the internal states being driven by both short- and long-term goals. These goals determine behavioural criteria (e.g., speed, accuracy, order etc.), with these criteria continuously adjusted to align with desired goals (Hockey, 1997). The target state (i.e., desired goals) is modified depending on the costs and benefits of alternate goals and behaviours. The model itself is a negative feedback system, with control achieved through comparison of the current state with the desired goal objectives and modifications as necessary to remove any discrepancies.

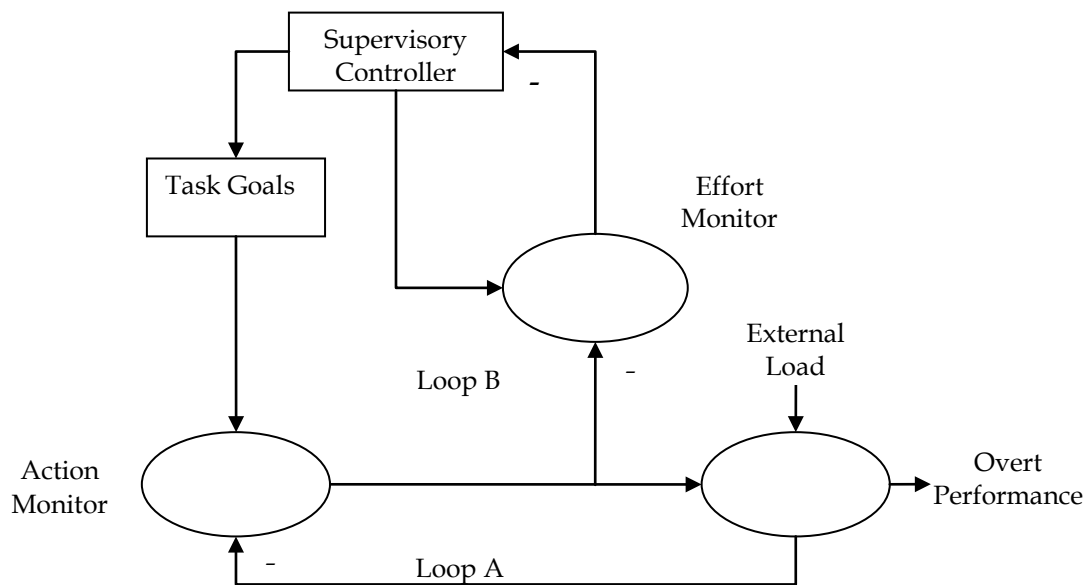


Figure 4.4.1: Hockey's Compensatory Control Model.

Source: Hockey (1997)

The lower loop of the Compensatory Control Model (Loop A) reflects the automatic and effortless processes that underlie skilled and well-learned tasks and behaviour. Comparison between current and objective stages is carried out through the action monitor, which automatically initiates necessary adjustments to enable optimal performance with minimal energy expenditure. This is achieved through changes in performance speed, timing, and use of working memory (Hockey, 1993, 1997).

When the effort to maintain performance via automatic control becomes too high, the upper loop of the model (Loop B) becomes involved and controls the allocation and expenditure of effort used in achievement of the goals. Transfer of control to the upper loop occurs when the effort monitor determines demands on the lower loop are too high. The supervisory controller then takes over, allowing a person to engage in controlled processing. This involves conscious changes in effort expenditure, desired goal state, or (though this is rare) total task disengagement. Changes in the goal state may be achieved through modification of the task requirements themselves or strategies used to achieve the desired goals. Essentially, the supervisory controller determines the costs and benefits associated with different ways of achieving the goal state and/or managing task load. Effort is then allocated according to priorities set by the supervisory controller (Hockey, 1997).

Loop B uses direct and indirect control. Direct control is achieved through increased effort expenditure to achieve desired goals. In order to maintain homeostasis, this increased effort is accompanied by an increase in sympathetic nervous system activity and an increase in subjective strain (Hockey, 1993, 1997). Hockey (1993) suggests that the sustained mental effort required to perform a task may be the main cause of mental fatigue. Indirect control is achieved through modification of the task objectives and/or

strategies. This involves a cost-benefit analysis of the impact of performing at specified levels and, although it is rare for a person to abandon the task itself, they often modify time pressures and task strategies, and/or engage on narrowed attentions such that all their cognitive resources are focused on what they determine to be the key task at hand. The concept of the human engaging in a trade-off between efficiency and thoroughness is consistent with Hollnagel's Contextual Control Model (COCOM) (see e.g., Hollnagel, 2004). A sustained lack of equilibrium results in a person experiencing a state of chronic strain accompanied by increased effort, reduced performance, increased anxiety, cognitive strain, and a sense of loss of control (Hockey, 1993, 1997).

The Compensatory Control Model is consistent with both Selye's (1936) General Adaptation Syndrome and the Maximal Adaptability Model (Hancock & Warm, 1989). Like these, it considers inputs, adaptation, and outputs and considers that people can adapt to stressors within their environment to achieve goal objectives. However, the Compensatory Control Model also provides some insight as to how a person may achieve their objectives, totally or partially, despite the fact they may be experiencing strain due one or more environmental stressors. The model also identifies some mechanisms by which adaptation occurs to maintain a state of equilibrium.

#### 4.5 Four-Stage Model of Stress and Performance

The role of the Supervisory Controller in Hockey's (1993, 1997) Compensatory Control Model is akin to appraisal of the situation and consideration as to the extent of the threat and availability of resources to meet the desired objectives. This role of appraisal is more clearly articulated in the Four-Stage Model of Stress and Performance (Salas et al., 1996, see Figure 4.5.1).

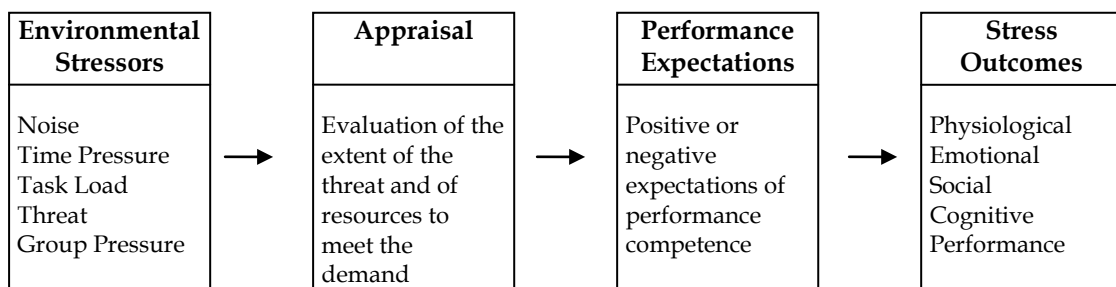


Figure 4.5.1: Four-Stage Model of Stress and Performance

Source: Salas, Driskell and Hughes (1996).

According to Salas et al. environmental stressors include factors such as noise, time pressure, task load, threat, and group pressure. When one or more of these stressors become relevant to a person they are then appraised. Appraisal itself may be primary or secondary. Primary appraisal refers to evaluation as to how threatening the stressor is; secondary appraisal is evaluation of the capacity of the person to deal with the threat. The appraisal process also allows a person to see the stressor in a positive light (i.e., resulting

in eustress e.g., by presenting a challenge) or a negative light (i.e., something that creates strain and therefore distress). As a consequence of appraisal a person develops performance expectations (i.e., belief in their ability to do what is required or not). If they believe they have the resources to cope with the perceived threat then a person has positive performance expectations. On the other hand, if they believe they do not have the resources the performance expectations are negative. Salas et al. argue that the belief that they can execute the task is important if a person is to perform well in situations of high demand.

According to the Four-Stage Model of Stress and Performance, performance expectations determine the stress outcomes. These outcomes include physiological responses, emotional reactions, social behaviour, cognitive effects, and performance outcomes.

- Physiological responses include:
  - sweating
  - muscle tension
  - changes in cortisol levels
  - heart rate changes
  - changes in brain activity.
- Emotional reactions include feelings of:
  - tension
  - frustration
  - fear
  - anxiety
  - concern for their own and others' safety.
- Cognitive effects include:
  - narrowing of attention
  - increased reaction time
  - increased errors
  - memory difficulties
  - response rigidity.
- Social consequences include:
  - decreased co-operative behaviour
  - increased aggression
  - and reduced altruism.

- Performance outcomes include:
  - decreased accuracy
  - reduced speed
  - increased variability.

Wilson, Braithwaite and Murphy (2003) illustrate how Salas et al.'s Four Stage Model of Stress and Performance can be applied to the military environment (see Figure 4.5.2). A variety of stressors are present in the battlefield and these acquire a positive or negative meaning to soldiers through appraisal mechanisms. Wilson et al. argue that if soldiers believe the situation is uncontrollable and/or uncertain (i.e., chaotic), then they will think they are unable to perform as required and/or change their situation. This will result in adverse stress outcomes, for example, performance will deteriorate. Wilson et al further argue these outcomes result in the "fog of war", that is, uncertainties with respect to one's own capability, the enemy capability, and enemy intent.

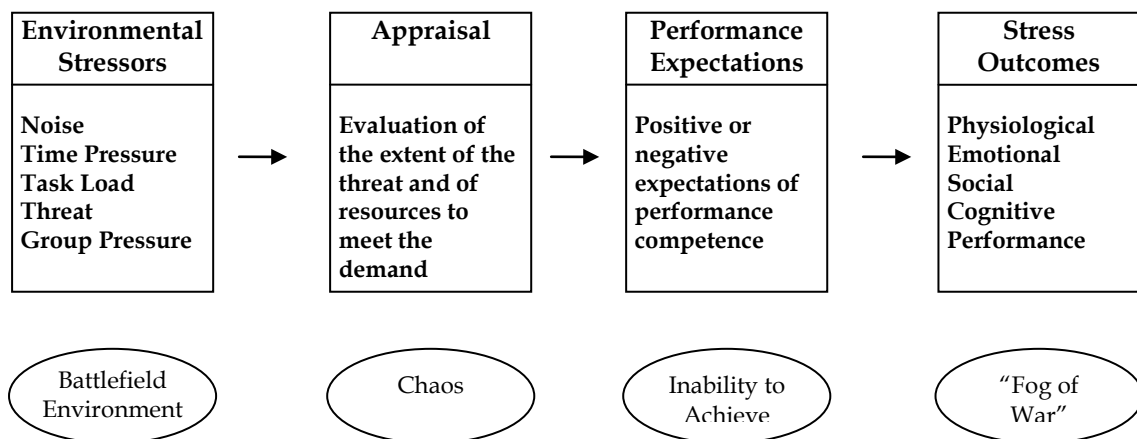


Figure 4.5.2: Wilson et al.'s application of the Four-Stage model to the Military Environment

Source: Wilson et al. (2003).

The General Adaptation Syndrome, Maximal Adaptability Model, and Compensatory Control Model identify that adaptive mechanisms compensate for disruption to homeostasis as a result of exposure to stressors, and the Compensatory Control Model explains the processes underlying this adaptation. Although the Four-Stage Model of Stress and Performance explains how appraisal mechanisms can determine the perception of a stressor and its impact on performance, it explains appraisal in terms of a person's perception of their ability to achieve their goals given the stressors they are exposed to. None of the aforementioned models adequately explain the manner in which a person may construe a stressor as having a positive or negative valence.

Gaillard (2008) suggests motivational factors explain why some people achieve optimal performance under a high level of arousal, whereas suboptimal performance may occur at

moderate arousal levels. Gaillard asserts research on work performance indicates that a person's performance depends on a balance between positive and negative factors. Positive factors are motivators, such as rewards, feedback, interesting work, stimulating environment, and social support. Negative factors are inhibitors and include stress, fatigue, and distractions. According to Gaillard, stressors include time pressure, unpredictability, ambiguity, conflicts, loss of control and threat; fatigue includes time on task, time awake, time of day, fitness, whether the job is boring, and a monotonous environment; and distraction includes interruptions, drawbacks, personal and/or conflicting goals and plans, and other motives. Gaillard's work indicates that demanding conditions may upset the equilibrium of positive and negative factors and thus result in a feeling of being overwhelmed. This concept is compatible with the models of Hancock and Warm (1989), Hockey (1993, 1997), and Salas et al. (1996) in that it provides further explanation for why some people may be able to mobilize more resources to maintain job performance whereas others do not.

#### **4.6 Process Model of Stress and Performance**

Hancock et al. (2001) developed a Process Model of Stress and Performance, which they argue provides a descriptive framework showing the relationship between stress and performance. This model incorporates features of the theories and models identified in the previous sections of this paper. It considers both physical and cognitive forms of stress, their interactions, and adaptations to stressors (see Figure 4.6.1).

The Process Model of Stress and Performance preserves the input, adaptation, and output components of the previous models in that it considers task or environmental demands (Inputs), compensatory responses (Adaptation), and performance (Output). However, it is more comprehensive and shows the differential impact of environmental and task demands on physiological and cognitive systems. For Hancock et al. environmental demands primarily determine physiological responses and task demands mainly influence the cognitive response. The physiological response has two components. A system specific component reflects the response of a specific physiological system to the input (e.g., thermal inputs activate the thermoregulatory system). The overall system is also impacted by the effects of stress. In other words, it is impacted by allostatic processes involved in regulation of specific physiological systems. If a specific system has sufficient capacity to respond to a stressor then an automatic adjustment is made in an effort to restore homeostasis. However, if the demands of the stressor exceed the capacity of a specific system the overall physiological system is engaged. If there are sufficient resources in the whole system, automatic compensatory processes are invoked to restore homeostasis. However, if the demands are too great, then a person becomes consciously aware of their current state and adaptations occur as a result of effort-full decision-making.

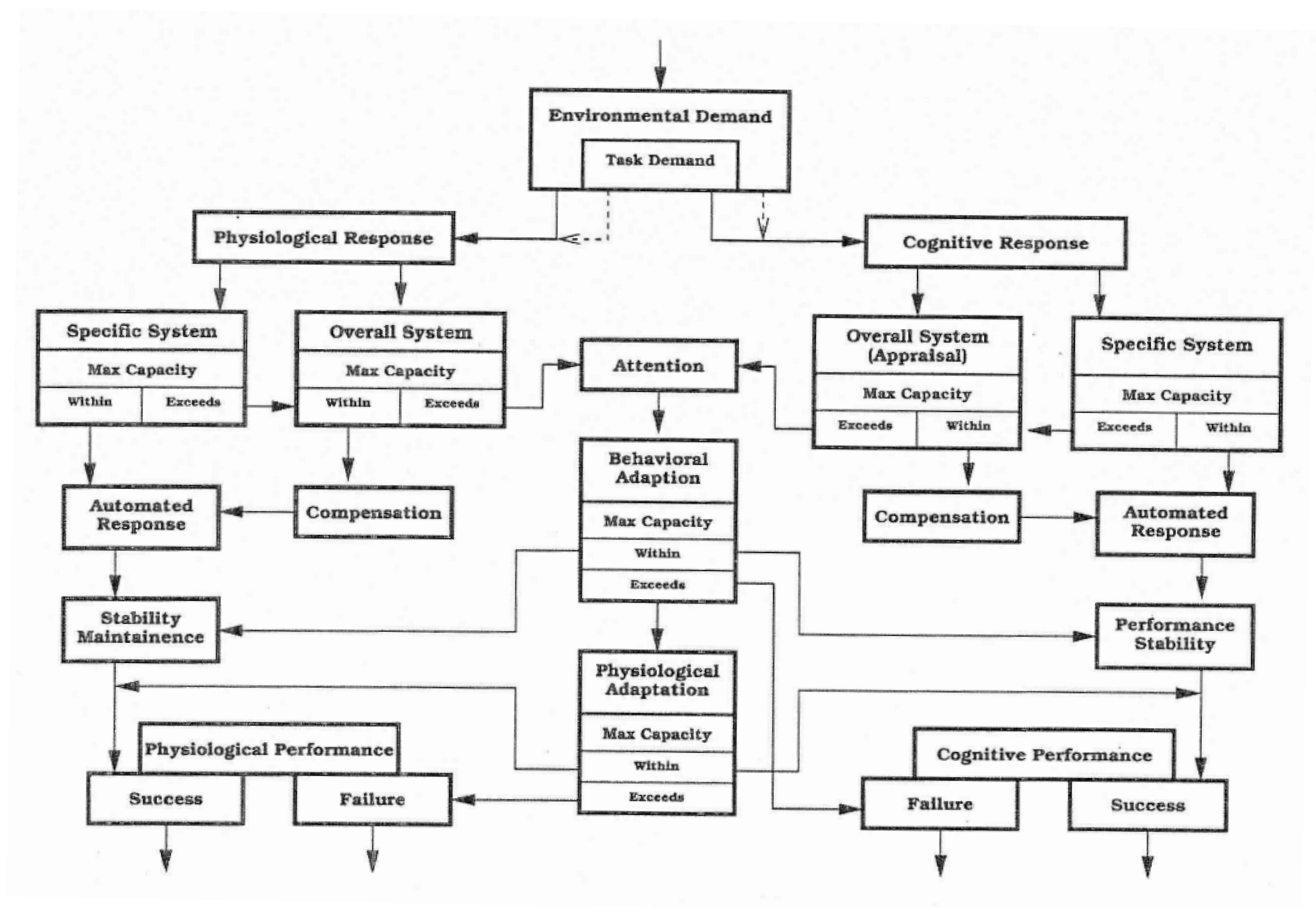


Figure 4.6.1: A Process Model of Stress and Performance

Source: Hancock et al. (2001).

Hancock et al. (2001) see the cognitive response occurring in much the same way as the physiological response. Initially a specific system (e.g., visual) is invoked and as long as demands do not exceed cognitive capacity, the person automatically adapts to response demands to restore homeostasis. However, if the resource demand is too high then conscious attention is required to appraise the stressor and its effects and determine the appropriate course of action to maintain (or restore) performance stability. Simply stated, when task demands are unable to be handled through automatic processing, both the physiological and cognitive systems invoke conscious attention and controlled processing mechanisms. According to the Process Model of Stress and Performance, adaptation encompasses a range of options ranging from a conscious decision to focus on specific aspects of the task through to actual task shedding. An advantage of this model is that it demonstrates how physiological and cognitive responses to stressors can interact. Basically, the Process Model of Stress and Performance identifies how environmental and task demands may overwhelm the capacity of the overall system to engage in automatic physiological and/or cognitive responses. It also demonstrates how physiological and cognitive responses compete for attentional resources when conscious effort is required. For example, a person may be working well on a complex task in a climate controlled environment. If this climate control fails such that the temperature becomes extreme, then

the person's attention is divided between their physiological state and the task they are involved in.

#### **4.7 Allostasis and Allostatic Load**

Rather than focusing on homeostasis, McEwen (1998) considers the processes involved in modifying other physiological parameters, and specifically focuses on the characteristic stress response: activation of the autonomic nervous system and the hypothalamo-pituitary-adrenal (HPA) axis. He used the concept of allostasis to refer to the production of hormones and other mediators modulated to maintain homeostasis. McEwen then identified that if a person is repeatedly exposed to physiological and/or psychological challenges, then allostatic overload can occur as the adaptive process of allostasis is not terminated. This allostatic overload produces wear and tear on the body and brain due to the constant exposure to stress hormones and mediators or the inadequate activation of these when required due to depletion of the body stores required to reproduce them. The consequence of allostatic overload is deterioration of physical and cognitive performance, including a potential inability to react to danger, and increased risk of physical and mental illnesses (McEwen 1998, 2003, 2007; McEwen & Stellar, 1993; McEwen et al., 1997).

#### **4.8 Summary of Stress Theories/Models**

The theories and models briefly reviewed above have a common factor in that they consider that performance is a function of the level of strain a person feels. With the exception of the Yerkes-Dodson Law, all consider that people are able to adapt to the impact of stressors so that they can achieve required goals. Further, the ability to compensate for a loss of homeostasis due to a stressor (or stressors) is due to the way in which a person appraises their situation and the resources available to them to deal with the situation and achieve their desired objectives. As Gaillard (2008) identified, whether a stressor acquires a positive or negative meaning also depends on other factors such as positive motivators and overall motivation levels. The complex nature of stress and lack of a conclusive definition of the phenomenon is reflected in the fact there is no authoritative theory or model of stress and its impact on human performance. Nonetheless, extant theories are characterised by two main concepts, which are an appraisal mechanism and adaptation.

The appraisal mechanism allows people to evaluate the impact of events on their psychological and/or physiological well-being and determine ways in which they can cope with demands placed upon them.

Adaptation mechanisms compensate for a loss of homeostasis to provide resources necessary for a person to maintain task performance. As adaptation utilises psychological or physiological resources, performance is maintained at a cost of these resources (Hancock & Szalma, 2006; Hancock & Szalma, 2008).

#### 4.8.1 Limitations

Our understanding of the impact of stress on performance is still limited. Hancock and Szalma (2008) argue this is largely due to four factors:

- Firstly, the theories and models that best explain the impact of stress on performance centre on the availability of resources and there is still a lot of uncertainty about cognitive resources (e.g., what they actually are, how they are depleted, how they are replenished);
- secondly, our understanding of appraisal mechanisms is still being developed;
- thirdly, although research has indicated that the response to a stressor is related to duration of exposure to the stressful event, few studies have investigated the effect of changes in both the environment and cognitive state over time; and
- finally, although we have a relatively good understanding of the effect of some stressors and standards exist with respect to these (e.g., noise, thermal exposure, vibration), our understanding of the interaction of stressors is limited. This is despite the fact that a large amount of human activity occurs in the context of more than one stressor.

Thus, more research is necessary to (a) further our understanding of the nature and mechanisms of cognitive resources; (b) increase our understanding of appraisal mechanisms and how they can help us better understand cognitive mechanisms related to the stress response; (c) demonstrate the effect of environmental and cognitive changes over time and the consequences of this effect for a person's adaptation to stressors; and (d) increase our understanding of how stressors interact and the consequence of these interactions on human performance. As Hancock and Szalma (2008) also identify, this research needs to be carried out in realistic situations in which people are exposed to real stressors.

The following section identifies some of the Inputs (environmental and task stressors) that a soldier may face during operations.

## 5. Inputs

As Hancock and Szalma (2008) identify, if we want to be able to predict soldier performance during complex and dynamic military environments, we need to understand how the various stressors interact and impact on performance. Nonetheless, in order to understand the interaction of stressors, we first need to identify operational stressors and their potential impact on performance. The perceived threats and danger from the populace, and/or the ambiguity, uncertainty and complexity of the environment within which they are operating, can potentially disrupt the soldiers' equilibrium. This may be compounded by the fact that military operations occur in extreme environments (e.g., thermal extremes, high altitude) in which they are likely to have to carry heavy

loads and be exposed to factors such as sleep deprivation, sleep loss, disruption of circadian rhythm, noise, and vibration (Forster, 2010).

According to Wilson et al. (2003) military personnel may be exposed to physical stressors (i.e., due to external environmental demands) or psychological stressors (i.e., distress resulting from the internal environment as a response to e.g., isolation, boredom and perceived threat). Irrespective of whether a stressor is physical or psychological, it represents an environmental or task demand on a person and elicits a physiological and/or cognitive response. Thus, it is an Input to the system. Research findings indicate that stressors – albeit physical or psychological – can impact on cognitive readiness (e. g., attention, reaction time, vigilance, memory, situation awareness, decision making) that is essential if a soldier is to perform well (Lieberman, Caruso et al., 2006). It is important to understand how factors in the operational environment impact on a soldier's performance. This will enable identification of mitigation strategies that can be employed to maximise performance in the field, as well as the potential impact of introduction of new equipment, technologies, doctrine, and/or operating procedures.

## 5.1 Physical Stressors

This section defines those key physical stressors (Inputs) that have been the subject of, in some instances extensive, research in the military context: noise, thermal extremes, vibration, sleep deprivation/fatigue, and protective clothing. Load carriage may also impact on performance; however, the majority of work in this area investigates the impact of load carriage on a soldier's mobility, rather than cognitive performance.

### 5.1.1 Noise

Noise is a psychological construct, defined as an unwelcome sound that the listener perceives as disruptive, unpleasant, and/or potentially harmful (Cohen & Weinstein, 1981; Salas et al., 1996). Researchers investigating the impact of noise often differentiate between "sound", the physical changes in air pressure detected by the ear structures, and "noise", the psychological impact of an auditory stimulus (Cohen & Weinstein, 1981; Salas et al., 1996). From a sound perspective, auditory stimuli may damage the ear structures and the resulting sensory loss may impact on performance. Indeed, although they wear hearing protection, there are numerous reports of soldiers experiencing stress as a result of hearing loss during operations (Krueger, 2008). Although sound-related damage may be a source of stress to the soldier the impact of the damage on performance is reasonably clear. A person cannot react to a stimulus they cannot hear. This paper therefore focuses on noise, the psychological impact of an auditory stimulus. Noise can disrupt homeostasis, disrupt sleep, decrease motivation, and interfere with cognitive and psychomotor performance (see e.g., Babeu & Cameron, 2005; Patil, Modak, Choudari & Dhote, 2011).

### 5.1.2 Climate

Climatic factors include ambient temperature, wind speed, humidity, rain, solar radiation, and altitude (Simon, Daanen, Lotens, Dutman, & Pasma, 2010). Unlike noise and vibration, temperature ranges from extreme cold to extreme heat, with both of these

impacting on human well-being. Modern military operations are largely occurring in environments subject to thermal extremes, for example, in Afghanistan temperatures can regularly exceed 40°C (Krueger, 2008), or drop as low as -24 °C ([http://en.wikipedia.org/wiki/Geography\\_of\\_Afghanistan](http://en.wikipedia.org/wiki/Geography_of_Afghanistan)). Thermal balance within the body is a factor of ambient temperature, clothing, exercise intensity and acclimatisation (Simon et al., 2010). There is an optimal heat range within which human performance is effective. If ambient temperature is higher than skin temperature the body gains heat, with heat loss occurring when the ambient temperature is lower than skin heat (Simon et al., 2010). Heat loss can be compensated for by additional clothing. However, heat gain is overcome by physiological adaptation, such as sweating. Excessive sweating can lead to dehydration (Lau, 1996; Simon et al., 2010). However, it is more complex than this.

People can acclimatise to extreme weather conditions, as evidenced by populations habitually dwelling in hot (e.g., Iraq) or cold (e.g., Greenland) environments. Moreover, the impact of temperature on an individual's performance depends on both the core body temperature and the environmental temperature (Hancock, Ross & Szalma, 2007). Although there are several means of measuring climatic conditions (e.g., thermometers), the internationally accepted climatic index is the wet bulb globe temperature (WBGT), which is a composite temperature that estimates the effects of humidity, air temperature, and solar radiation on people (Hancock et al., 2007; Simon et al., 2010). With respect to climate, this paper considers the impact of thermal stress on performance, with a focus on research that has used the internationally accepted climatic index of the WBGT.

### 5.1.3 Motion

Military vehicles are built for functionality and not comfort. They are also often driven in adverse road conditions. Motion refers to movement of the vehicle in a range of directions (e.g., forwards, backwards, sideways, vertical). Vibration is a subset of motion represented by a shaking motion. Whole body vibration (WBV) occurs as a result of vehicle vibrations being transferred to vehicle occupants (Nakishima & Cheung, 2006) and consists of roll (left-right movements), pitch (forward-backward movement), and heave (up-down movement or vertical displacement) (Demczuck, 2011; Nakishima & Cheung, 2006). WBV is usually measured in terms of "the root-mean-squared acceleration, in units of m/s<sup>2</sup>" (Nakishima & Cheung, 2006). Soldiers are routinely exposed to whole body vibration whilst in vehicles that do not have suspension systems that dampen the vibrations (Merlo, Szalma, & Hancock, 2008). They are also exposed to whole body vibration from the recoil of weapon systems. Although the nature of vibrations to which a person is exposed is complex, the ISO (1997) regards the vibration frequency range 0.5 to 80 Hz as important for human welfare (Nakishima & Cheung, 2006). However, as Nakishima and Cheung identify, these standards consider the impact of vibrations on a person's health and welfare, not their performance. Soldiers are often exposed to the impacts of motion (e.g., during transit, and whilst in command and control vehicles). Motion and vibration have been shown to impact on performance, and vibration can create fatigue (e.g., Lin, Hsieh, Chen & Chen, 2008). It is therefore important to identify the impact of vibration on performance.

#### 5.1.4 Sleep Deprivation

Sleep can be defined as “a reversible behavioural state of perceptual disengagement and unresponsiveness to the environment” (Carskadon & Dement, 2011). The amount of sleep required each day decreases over our life-time. Although there are individual differences, young adults less than 25 years generally require around 8.5 to 9.25 hours per night for optimal functioning, whereas those over 25 years require around 8 hours sleep per night (Miller, Matsangas & Shattuck, 2008). This general 8-hour period includes about 3-4 hours of rapid eye movement (REM) sleep with the balance being non-rapid eye movement (NREM) sleep (Carskadon & Dement, 2011; Spiegel, Leproult & van Cauter, 1999), with REM sleep normally occurring during the latter stages of the 8-hour sleep period. NREM sleep consists of periods of light and deep sleep. Humans’ alertness levels are determined by circadian rhythms such that we are predisposed to sleep during the night time and work during the day. This sleep propensity is also linked to our core body temperature, which decreases at night time and increases again in the morning (Carskadon & Dement, 2011; Miller et al., 2008). REM sleep generally occurs when the core body temperature is at its lowest during the early morning time frame. When sleep is delayed (e.g., due to shift work) such that people are unable to sleep until the early morning when their core body temperature is low, the sleep pattern is disrupted and REM sleep occurs much earlier (Carskadon & Dement, 2011). If people are totally sleep deprived then they experience an increase in both REM and deep NREM sleep, with REM taking precedence over NREM.

Military operations inevitably involve extended periods of work, with greatly reduced opportunities for sleep. They often also include irregular working days and different shifts. The long days and variable shifts mean personnel are inevitably exposed to sleep deprivation. This is compounded by military also engaging in continuous operations (ConOPS) and sustained operations (SUSOPS). ConOPS allow rest periods of 3-5 hours in a 24-hour period. In SUSOPS, soldiers are engaged in ConOPS with no relief and little chance of getting more than a few minutes rest (Orasnu & Backer, 2006). Both acute sleep deprivation (e.g., due to a 24 hr military exercise) and chronic sleep deprivation (e.g., due to several nights of restricted sleep) can result in sleep debt, which can in turn create an irresistible compulsion to sleep. Although the exact purpose of sleep remains unclear, the fact that the amount of both REM and deep NREM increase following sleep deprivation suggests that both these forms of sleep are essential in some way. Accumulating evidence tends to suggest that NREM sleep fulfils a restorative function (see e.g., Markov & Goldman, 2006), whereas REM sleep enhances memory consolidation (see e.g., Karni, Tanne, Rubenstein, Askenasy & Sagi, 1994; Stickgold & Walker, 2005). Thus, sleep deprivation can interfere with both physiological well-being and cognitive performance, including the integration of new information into existing knowledge.

#### 5.1.5 Fatigue

Like stress, fatigue is a poorly defined phenomenon. Nonetheless, it can generally be regarded as a decrease over time between available resources and those necessary resources to perform a task (Akerstedt et al; 2004; Smets, Garssen, Bonke, & de Haes, 1995). If a person is sleep deprived they are likely to feel sleepy, as well as fatigued due to the lack of necessary resources to function adequately. People can also experience physical fatigue through prolonged activity (e.g., they feel they cannot move any further) or

cognitive fatigue (e.g., an inability to concentrate). Fatigue can also be acute or chronic, a result respectively of short-term and long-term demands on physiological or cognitive resources. Due to its slower build up, the impact of chronic fatigue is more insidious and harder for a person to detect until too late (Collyer, 2003; Miller et al., 2008). Nonetheless, both forms of fatigue can affect a person in much the same way as excess alcohol can impact on a person's ability to attend to environmental stimuli. An important point here is that fatigue can occur as result of prolonged exposure to one or more stressors, and can be independent of sleep deprivation.

As both sleep disruptions and fatigue can characterise military operations it is important to identify the impact of both of these (both independently and in combination) on soldier performance. Therefore, Section 7 of this paper provides an overview of the impacts of these on performance.

#### 5.1.6 Protective Clothing

Protective clothing available to soldiers includes the Disruptive Pattern Combat Uniform (DPCU) that provides camouflage in specific environments, Combat Body Armour (CBA), chemical protective clothing, and Combat, Biological, Radiation and Nuclear (CBRN) protection. DPCU is akin to conventional attire in that it allows evaporation of body sweat and is not over bulky. However, the protection afforded by CBRN, chemical protective clothing and CBA comes at the cost of compromising thermoregulatory mechanisms within the body, potentially increasing thermal strain on the soldier (Amos, Cotter, Lau, Forbes-Ewan, 1998; Caldwell, 2008; Krueger & Banderet, 1997). Moreover, the extra bulk of CBA and chemical protective clothing is likely to impact on a person's mobility and agility. The ADF have to make a trade-off between protection afforded by such clothing and its impact on task demands, such as mobility. As protective clothing has the capacity to exacerbate the impact of hot environments as well as create distress in a soldier due to restrictions on their movement, Section 7 of this paper provides an overview of the impacts of protective clothing on performance.

## 5.2 Psychological Stressors

This section defines identified psychological stressors (Inputs). In the context of performance, rather than mental health, these psychological stressors have been the most extensively researched: mental workload, threat, time pressures, and role ambiguities (Bowers, Weaver, & Morgan, 1996). This paper focuses on mental workload, although acknowledging that ambiguities, isolation, sense of danger and/or threat, and perceived loss of control have also been identified as potential stressors that interfere with a soldier's state of equilibrium (Bartone, 2006).

### 5.2.1 Mental workload

Mental workload is a psychological construct referring to a phenomenon separate from behaviour and performance (Parasuraman, Sheridan & Wickens, 2008). Simply put, mental workload is the amount of cognitive resources required to perform a task. If there are less cognitive resources available than the task requires, then cognitive overload can occur. Apart from being in a complex and dynamic operational environment, modern soldiers

are also faced with new technologies designed to help them do their job better and/or provide them with more information. The concept of the network-enabled force provides soldiers with a wealth of information, often without the time to process. Modern technology compounds the demands imposed by uncertainties in the modern operational environment. Soldiers have to be able to deal with cognitive complexity, ambiguity and engage in sound decision-making right down to the level of the private soldier, prompting the phrase “strategic private” (Schmidtchen, 2007). Decisions may need to be made even though soldiers are faced with a lot of information and insufficient time to process it effectively.

It is vital that technology does not contribute to allostatic load due to factors such as poor design, inadequate systems and physical integration, or excess weight (Hancock & Weaver, 2003). For some United States Army personnel, much of the tactical information is provided via use of helmet and head mounted displays. Currently, these are not widely used within the ADF but are likely to be in the future. Although the intent of providing the information is to aid mission success, the amount of information increases demands on cognitive resources and increases cognitive workload. Moreover, if the equipment is cumbersome or unreliable this increases the strain on the user (Hiatt & Rash, 2009).

Collectively, the modern operational environment means soldiers are increasingly likely to have greater cognitive demands placed upon them. As these increased demands can impose a burden on mental resources, mental workload is likely to be a cause of distress to the soldier. Section 7 provides an overview of research summarising the potential impact of mental workload on performance.

### 5.2.2 Other Factors

Other factors include isolation, ambiguity, a sense of powerlessness, perceived threat or danger, and boredom. Bartone (2006) identified soldiers can feel isolated as a consequence of being away from friends and family, being in a new environment in which people have different cultural values and attitudes, having unreliable communication systems, and being part of a new unit. Ambiguities with respect to their roles, mission objectives, necessity for the operation to which they are deployed, and differing rules of engagement amongst coalition members were also identified as factors that contributed to soldier distress (Bartone, 2006; Wilson et al., 2003). As a consequence of their operational environment, soldiers also experience a heightened level of threat and/or danger. Irrespective of whether this represents the true nature of their environment or their perceptions of their situation, soldiers’ arousal levels are increased as a consequence of perceived threats and/or danger (Bartone, 2006; Krueger, 2008; Orasnu & Backer, 1996). Related to both ambiguities and perceptions of threat and/or danger is a perceived loss of control, that can also threaten a soldier’s equilibrium. This feeling of not being in control is likely to be present in all deployments even though the trigger may be different. For example, it may be due to uncertainties associated with fighting in the asymmetric environment or arise in peacekeeping operations as a consequence of rules of engagement not allowing soldiers to intervene in situations that would usually be resolved with military force (Bartone, 2006; Wilson et al., 2003).

Finally, soldiers deployed on operations often experience large periods of inactivity between times when they are operating at a frenetic pace. Prolonged inactivity often results in boredom, which can also be distressing to the soldier (Bartone, 2006).

The aforementioned factors can all increase the soldier's arousal level, as well as affecting factors such as motivation and morale, and thus compound the impact of other inputs on their homeostatic state. Although they are not addressed in further detail within this paper, they are important and should be considered as extraneous factors in any research investigating the impact of new capability, or environmental and task demands, on performance.

### 5.3 Summary of Inputs

With the exception of the other factors identified immediately above, the aforementioned factors in the external and internal environment identified in this section have all been the subject of intensive research. They can all be seen as Inputs that evoke processes involved in allostasis, and research findings generally indicate that they have detrimental effects on a person's performance. Before summarising key findings with respect to their impact on performance, the next section provides an overview of ways in which people adapt to the imbalance of homeostasis that arises as a consequence of environmental inputs and task demands.

## 6. Adaptation

As identified when reviewing relevant key theories and models of stress, mechanisms exist that allow a person to adapt to repeated exposure to stressors. These adaptations can be the result of processes internal to the person (endogenous), such as allostasis, or interventions external to the person (exogenous). Endogenous adaptations may occur automatically as a result of physiological responses or subconscious cognitive processes (unconscious volition), or as a result of conscious volition. Irrespective of the nature of the input that disturbs the internal steady state, the available adaptation mechanisms themselves are the same. What may differ are the mechanisms invoked by the input at a particular point in time.

This section summarises ways in which the adaptation process may occur, as well as strategies that can be used to maximise adaptation to an input that has upset a person's equilibrium. Endogenous processes to be considered include physiological responses, cognitive responses (e.g., narrowing of attention, motivation, resilience), and personality factors. Exogenous interventions include training per se and use of ergogenic aids. The latter are factors external to the person that can be used to improve physiological and mental performance. Ergogenic aids can include factors such as mechanical aids, psychological aids, pharmacological aids, and nutritional aids. As the military are currently using pharmacological and psychological (e.g., resilience training) aids, this section focuses on these. This section also provides a brief overview of the role of adaptive

automation in reducing the homeostatic imbalance created by one or more environmental inputs.

## 6.1 Internal Adaptation Responses

The internal adaptation responses broadly involve physiological and cognitive responses that occur in an effort to restore the body to a state of balance. Although both kinds of responses are automatic, cognitive adaptations can also be due to conscious decisions to adapt behaviour as a result of the disruption in their internal steady state.

### 6.1.1 Physiological Responses

Cannon (1929, cited in Zimbardo, 1992) identified a set pattern of physiological changes within mammals when they are faced with perceived threat or danger. He called this the “fight or flight” response. Essentially, activity occurs within the body to prepare it for escaping from perceived danger or staying to confront it. This response involves a redistribution of resources within the body so these are maximised in areas that will be utilised in either fleeing or fighting. This mobilisation of resources is underpinned by activation of the endocrine and autonomic nervous systems within the body. These two systems work together to support the fight or flight response, and also the adaptation responses that allow restoration of homeostasis when this has been disrupted by perceived threats.

The endocrine system is largely responsible for ensuring the body has the correct amount of hormones and the autonomic nervous system is primarily responsible for controlling restorative (e.g., eating) and energetic (e.g., running) functions. Together, these systems regulate the flow of adrenalin, a hormone that increases heart rate and reduces activation in the stomach and intestines; and noradrenalin, a hormone involved in regulation of glucose, the body’s key energy source. As a result of increased adrenaline, the fight-or-flight response is evidenced by tensing of muscles, increased breathing and heart rate. Cortisol is another hormone that is released as a result of action of the endocrine system and works with noradrenalin and adrenalin to ensure sufficient glucose is available for the person to do what is necessary to respond to the perceived threat or danger. Cortisol also has a regulatory role via feedback loops that allows it to turn off the flight or flight response so the body can return to a steady state. If the Input (stressor) that triggers the allostatic process is not removed, hormones released by the endocrine and autonomic nervous systems will accumulate. At some stage, the body has to return to a steady state or it will enter a state of exhaustion due to the inability to replenish adrenalin and glucose.

The fight or flight response can also be elicited by exposure to environmental inputs or task demands that result in a person experiencing distress. Chronic disruption to the homeostatic state through repeated exposure to perceived threat or danger, extreme environmental conditions, and/or task demands results in a breakdown of the regulatory mechanisms of the endocrine and autonomic nervous systems, and jeopardises the ability of these systems to restore balance within the body (McEwen, 1998; Guillems & Edwards, 2010; Khoozani & Hadzic, 2010; Previc, 2004; Selye, 1936; Tsigos & Chrousos, 2002; Zimbardo, 1992). These physiological responses to adverse environmental factors can be

measured. For example, through use of intrusive measures such as core body temperature, salivary cortisol, blood pressure, adrenalin, and noradrenalin; and non-invasive measures such as pulse rate, heart rate, heart rate variability, muscle contractions, ocular measures such as pupil size and blinking, voice dynamics, and brain activity (Khoozani & Hadzic, 2010; Previc, 2004).

### 6.1.2 Cognitive Responses

As well as the innate physiological responses to perceived threat or danger and excessive environmental and/or task demands, automatic cognitive processes occur that allow a person to more effectively deal with the task at hand. These responses are generally those that accompany well learned tasks (e. g., driving or shooting). There is an interaction between the physiological and automatic cognitive responses due to the accumulation of chemicals within the brain that enhance performance relevant to the situation. These chemicals heighten sensory processing, vigilance, focussing of attention on key aspects within the environment, motor speed, and rapid decision making processes that allow a person to accomplish what they need to do (Khoozani & Hadzic, 2010; Previc, 2004). Sometimes the environmental and task demands place too much burden on the person such that automatic responding is inadequate and/or they are overwhelmed by their situation. In this case, they may consciously decide to focus on specific aspects of the environment or task, such that their attention is narrowed and they may fail to observe other key features relevant to the task at hand. Irrespective of whether the cognitive responses are automatic or controlled, a person's cognitive responses can be measured by a variety of cognitive and performance measures (e. g., response time, accuracy, events detected, situation awareness, problem solving ability, time on task, dual task performance, working memory, and decision quality).

### 6.1.3 Other Internal Factors

Physiological and cognitive responses to events that disrupt a person's equilibrium can be affected by other factors such as their mood and personality characteristics. For example, research has shown that extroverted (outgoing) people generally have a lower base level of arousal than do introverts. This is why extroverts are more likely to seek situations that increase their arousal levels as opposed to introverts who, due to naturally higher base level of arousal, find such environments distressful. Thus, the stage at which an extrovert finds an environment or task too demanding is likely to occur later than the point at which an introvert will display discomfort and concomitant physiological and cognitive indicators of this distress. Other research indicates that the point at which a person becomes overwhelmed by environmental or task demands is also dependent on factors such as heightened sense of being able to control a situation, high motivation to achieve, and a belief in their ability to cope with adverse situations (Previc, 2004; Szalma, 2008).

Indeed, there is a growing body of research into the area of resilience (hardiness) aimed at understanding individual differences in response to adverse situations, as well as means by which a person might be trained to improve their degree of resilience; thus either slowing the onset of physiological and cognitive adaptations to demanding environments and/or task demands, and/or alleviating the disruption of the homeostatic state This

research indicates that the degree to which a person is affected by adversity or change within their environment depends on their level of commitment to the task, belief that they have control over events, and whether they see change or adversity as a challenge or opportunity and not a threat. As with physiological and cognitive responses, these personality factors can be measured (e.g. hardiness measures, coping styles, motivation, personality type, locus of control, and belief in their ability to perform a task [self-efficacy]) (e.g., Bartone et al., 2006; Bartone et al., 2007; Bartone, 2007; Bartone, Roland, Picano & Williams, 2008; Delahaij, Gaillard, & Soeters, 2006; Kobasa, 1979; Driskell, Salas, Johnston & Wollert, 2008).

## **6.2 External Adaptation Aids**

External adaptation aids are designed to negate or modulate the physiological responses to environmental inputs and/or equip a person with the necessary strategies so they find the situation less distressful and are better able to deal with it.

### **6.2.1 Training**

Empirical research has long established that well practised tasks result in automatic responding, which creates less demand on resources. Conventional military training ensures soldiers are well-drilled such that their dominant response in threatening or dangerous environments is the “correct” one, that is, one that will ensure achievement of command intent as well as maximise the survival of themselves and others. The army still needs regular training to promote acquisition and retention of essential skills and ensure that automatic responses will dominate when these skills are required. Continuous training beyond the stage of initial mastery increases the likelihood of automaticity and a corresponding demand on essential physiological and cognitive resources.

However, the changing nature of military operations, technological advances, and the fact that people enlisting in the army are increasingly savvy with information technology and technological advances have prompted a realisation that current training methodologies may be inappropriate for the soldier of the future. There has been a greater acceptance of the importance of the human dimension in warfare and the need for mental agility, intuition, cultural understanding, and resilience in order to achieve mission success (e.g., Mackey, 2008). Thus, although it is important that the military avail themselves of technological advances to retain a competitive edge, it is equally important that a soldier's functional state means they are capable of achieving optimal performance.

### **6.2.2 Resilience Training**

Resilience training is sometimes referred to as hardiness training or stress exposure training. Irrespective of the term, this type of training is designed to improve a soldier's ability to perform well when faced with adverse internal or external environments. Resilience training allows defence organisations to be proactive with respect to mitigation of the impact of stressors in the operational environment, not only on performance but also on factors such as mental health and retention. The importance of resilience training is evidenced by the U.S. Army's Comprehensive Soldier Fitness program (e.g., Casey, 2011)

and the Australian Defence Force BattleSMART initiative (e.g., Cohn, Hodson & Crane, 2010). These both identify the need to train soldiers so that psychological well-being is accorded the same importance by them as their physical status. The aim of resilience training is to reduce the physiological and cognitive demands on scarce resources so a person continues to perform effectively when their internal steady state is threatened.

Resilience training generally involves three stages:

- First, soldiers are informed of the changes within their body when faced with adversity as well as mechanisms (e.g., coping skills) they can use to overcome some of these effects. The purpose of this is to reduce the novelty of situations in which environmental inputs result in disruption of homeostasis, and to promote an understanding of the adaptive mechanisms that occur so people are prepared for them.
- Second, soldiers are trained in relaxation techniques, coping strategies, and metacognitive skills (the ability to understand and reflect on their own knowledge, awareness and response to the situation). The aim of this stage is to enhance a person's ability to deal with a situation and to understand the appropriate coping strategy at any particular point in time.
- The third and final stage involves application of the knowledge and skills they have acquired to a range of realistic environments. This is targeted at enhancing a soldier's belief in their capacity to cope with a range of situations, their understanding of how best to deal with any particular event that is potentially distressful, and their ability to make good decisions in demanding times (Delahaij et al., 2006; Driskell et al., 2008).

### 6.3 Pharmacological Interventions

Pharmacological interventions are designed to counteract the physiological responses to environmental inputs that initiate allostatic processes. Such interventions are commonplace within military operations and include sleeping tablets, caffeine and other stimulants. Sleeping tablets are used to overcome the disruptive effects of continuous operations resulting in chronic sleep loss, short-term intense and prolonged activities resulting in acute sleep loss, and shift schedules that reduce the amount of time available for sleep as well as requiring a person to sleep at a time when their circadian rhythm would have them awake. Stimulants used to counteract the effects of sleep loss and/or deprivation and fatigue include caffeine, modafinil, amphetamines, and a combination of zolpidem and caffeine. The latter combination allows the effects of a short-term sleeping tablet to be counteracted on awakening by those of a slow release stimulant. (see e.g., Caldwell & Caldwell, 2005; Killgore, Kahn-Greene, Grugle, Killgore & Balkin, 2009; Wesensten, Killgore & Balkin, 2005).

## 6.4 Adaptive Automation

Adaptive automation is a form of automation that allows tasks to be “dynamically allocated between the human operator and computer systems” (Byrne & Parasuraman, 1996). The aim of research in this area is to devise means by which technology may identify when a human is overloaded and automatically take over part of the task to reduce the burden on the person and allow the task to be performed more effectively. Alternatively, the human may voluntarily pass control of certain tasks to the technology. Either way, a central feature of adaptive automation is the appropriate allocation of tasks and/or task components between technology and the human to maximise performance outcomes. The technology changes its level of involvement and/or automation in accord with a person’s disengagement with the task for whatever reason (e.g., increased mental workload, sleepiness, fatigue, exertion etc.).

Reallocation of effort between the human and technology is believed to alleviate a person’s cognitive workload, as well as enhancing safety if the operator has disengaged from a critical task. Much of the work in this area is exploring the potential for psychophysiological measures to inform the operator or the technology when cognitive resources are likely to be exhausted. Complementary to this approach is research on unmanned vehicles (air, land, and sea) that can operate in situations that are inherently dangerous for humans as well reduce the burden on the soldier during operations. In essence, this is robotics and research is currently focused on trying to identify the level of automation that is necessary for robots to provide effective decision support and reduce the load on the operator (e.g., Desai, Stubbs, Steinfeld & Yanco, 2009).

## 6.5 Summary

Factors involved in the physiological adaptation response have been extensively researched for a large number of years. Our understanding of the role of hormones and transmitters in cognitive performance has also increased markedly as a result of intensive research. Further, our understanding of the role of other factors, such as personality, is aided by knowledge of the mechanisms involved in both the initial response to an environmental input or task demand that threatens homeostasis, as well as the physiological adaptations that occur. These personality characteristics underpinning differential responses to situations that are potentially threatening form the basis for the concept of resilience training, with this being rapidly recognised as a means by which military personnel can be equipped to perform more effectively in adverse environments. Our understanding of mental workload, sleep and fatigue and their associated brain changes are also enabling research in the area of adaptive automation. The use of pharmacological aids is also based on our understanding of the physiological responses as a consequence of loss of homeostasis, particular with respect to sleep deprivation, sleep loss, and fatigue.

Nonetheless, despite the advances that have been possible due to extant understanding of adaptation responses, there is still much we do not know. For example: the precise mechanisms by which the endocrine and nervous systems interact, the role of hormones

and neurotransmitters on cognitive performance, reasons for individual differences in brain functioning and the consequence of these, and brain mechanisms and/or structures involved in the cognitive responses. Further, although defence organisations may be using pharmacological aids, there is still much we do not know about the long-term impact of these aids on military performance and/or the long-term consequences for the soldier.

Further research is necessary to more fully understand how the adaptation processes help maintain effective physical and cognitive performance, means by which these processes can more effectively be utilised to identify when a person is approaching allostatic load, and mitigation strategies applied, and the extent to which adaptation processes mask the true impact of Inputs on performance.

Despite these qualifications, research in the area of adaptation responses has identified metrics that can be utilised to measure both physiological and cognitive adaptations. Together with performance measures, these can provide insight into the impact of Inputs (stressors) on soldier performance, and Adaptations that may be occurring to maintain performance levels. More importantly, they may also provide information into factors such as tasks that are focused whilst others are excluded, and trade-offs made in order to preserve performance on a task (e.g., time/accuracy tradeoffs). Measures include: heart metrics, core body temperature, pulse rate, salivary cortisol, brain activity, ocular metrics, glucose levels, voice dynamics, adrenalin, muscle movement, narrowing of attention, and situation awareness.

The next section commences with an overview of the impact of inputs, and adaptation to these inputs, on performance. It then provides a summary of key findings with respect to specific inputs identified in Section 5 as of key relevance to the military.

## 7. Outputs

The previous sections of this paper have summarised key theories and models of the stress concept, identified that ambiguities exist with respect to the stress concept, and that when a person talks about stress they are really talking about the way in which environmental or task demands upset a person's internal state (i.e., equilibrium), which results in a person feeling distressed with a concomitant impact on behaviour in some way. These environmental and task demands are seen as Inputs (commonly referred to as stressors) to the human system which then engages in adaptation processes that allow a steady state to be regained. As identified in Section 6, there are physiological and cognitive adaptation processes, many of which are automatic. However, cognitive adaptations may also be volitional and result in changing of priorities or task shedding. All of these adaptations can be measured in some way. It needs to be noted here that there is a large degree of overlap in the measures involved with respect to the psychological adaptations and those assessing output behaviours.

This section focuses on Outputs, which are the observable consequences of an Input and adaptation processes initiated to restore homeostasis which was disturbed by that Input. Specifically, it summarises the changes in essential cognitive functions as a consequence of

the key Inputs identified in Section 5: noise, climate, vibration, sleep deprivation/fatigue, protective clothing, and mental workload.

Despite extensive research on the impact of the physical stressors of noise, climate, motion, sleep deprivation/fatigue, protective clothing, and mental workload on performance there remains a lot of uncertainty. In some cases (e.g., noise) there are conflicting findings, with results ranging from impaired performance, no impact at all, to performance facilitation (Salas et al., 1996; Wilson et al., 2003). In other cases there are confounds that make it difficult to ascertain the impact of a particular Input (e.g., vibration research may confound equipment vibrations with the impact of vibration on a person; fatigue research far too often confounds sleep deprivation with cognitive fatigue).

*Table 7.1: Some critical soldier abilities and summary of research findings with respect to the impact of specified Inputs (Stressors) on these; increase (+), decrease (-), no change (<>), or uncertain (?).*

	Noise	Heat Stress	Cold Stress	Motion	Sleep Loss	Fatigue	Clothing	Mental Load	Sleep Drugs	Stimulants
Arousal	+				-					
Visual discrimination	?				-	-	-			
Psychomotor skills <sup>1</sup>	<>	?		-	-		-		-	+
Reaction time	?	?	?	+	+	+	+			+
Accuracy	?	?	?	-	?	?	?			
Attention										+
Perceptual tunnelling <sup>2</sup>	+					+		+		-
Cognitive tunnelling <sup>3</sup>	+				+	+		+		-
Vigilance <sup>4</sup>	-	?	?		-	-				+
Target detection	?					?	?			
Task shedding						+				
Memory	-	?	?		-	-				
Judgment/Decisions	-	?	?		-	-	-			
Verbal reasoning <sup>5</sup>	-	?				-	?			+
Numerical reasoning <sup>6</sup>	-	?			-					
Spatial reasoning <sup>7</sup>		?								
Task Prioritisation						?				
Effective Communication	-					-				

<sup>1</sup>Coordination of physical and cognitive activities (e.g., marksmanship)

<sup>2</sup>Decreased peripheral field of attention

<sup>3</sup>Reduction in salience (e.g., reduced situation awareness)

<sup>4</sup>Sustained and focused attention (e.g., observations; radar)

<sup>5</sup>Comprehension and use of written or spoken language

<sup>6</sup>Comprehension and use of numerical material

<sup>7</sup>Ability to form mental representations and manipulate these in the mind (e.g., navigation; identifying enemy/friendly locations)

Table 7.1 presents some essential abilities a soldier needs to ensure operational success, as well as an overall summary of research findings with respect to the impact of specific Inputs on these abilities. Specifically, whether Inputs have been found to increase,

decrease, or have no impact on these abilities; as well as whether the impact on performance is unclear from extant research. The critical abilities identified are: psychomotor skills, attention and vigilance, memory, judgment and decision-making, prioritisation of tasks, and communication skills (Rash et al., 2009), as well as visual discrimination.

## **7.1 Impact of Physical Stressors on Performance**

### **7.1.1 Noise**

The relationship between noise and performance is unclear. Research has yielded inconsistent findings, with results ranging from impaired performance, no impact at all, to performance facilitation (Bourne & Yaroush, 2003; Cohen & Weinstein, 1981; Salas et al., 1996, Wilson et al., 2003). To date, research data indicate the impact of noise on performance depends on the nature of both the noise and task used (see e.g.: Cohen & Weinstein, 1981; Conrad et al., 2010; Hancock et al., 2006; Ljungberg & Neely, 2007; Saeki, Fuji, Yamaguchi & Harima, 2004).

In general, early research indicated that performance was more likely to be degraded by noise levels above 95 dB; noise levels lower than this were more likely to either have no impact on performance or facilitate it (see e.g., Broadbent, 1971; Cohen & Weinstein, 1981; Suter, 1989). However, more recent research indicates that noise levels as low as 42 dB may also impact on performance (Waye, Rylander, Benton & Levanthall, 1997). Early research also indicated that performance was more likely to be affected by high frequency noise than by low frequency noise (see e.g., Broadbent, 1971; Suter, 1989). Nonetheless, Waye et al. (1997) found that the low frequency noise elicited by ventilation equipment also impacted on performance. Pawlaczyk-Luszczynska, Dudarewicz, Waszkowska, Szymczak & Sliwinska-Kowalska (2005) similarly found that low frequency noise (~50dB) commonly found in the work environment (e.g., generated by ventilation, air conditioning and computing systems) degraded cognitive performance and attention.

The impact of noise on performance also depends on the meaning of the noise to the individual and the social context within which the noise occurs (Cohen & Weinstein, 1981; Driskell, Mullen, Johnson, Hughes & Batchelor, 1992, cited in Salas et al., 1996). For example, Conrad et al. (2010) found that background classical music had no impact on accuracy of laparoscopic surgery experts, although they took longer to perform their task. Conversely, Saeki et al. (2004) found that, although participants found both meaningful and meaningless noise annoying, performance was more affected by meaningful noise, but only for an auditory as opposed to a visual task. However, as these researchers found noise impacted on performance speed and accuracy when stimuli were presented in the same modality as the noise (i.e., both were auditory stimuli), then performance decrements may be due to both the noise and task stimuli competing for resources within the same information processing system.

Further, with respect to the nature of the noise and its impact on accuracy and performance, research has indicated that noise perceived to be of an annoying intensity and duration results in a speed/accuracy trade-off, such that as response rate increases, so does the error rate (Hockey, 1979; Salas et al, 1996). This may be due to arousal levels

increasing to a suboptimal state and/or increased demand on cognitive resources (Hockey, 1979).

The speed/accuracy trade-off and differential impact of tasks was confirmed in a meta-analytical study undertaken by Hancock et al., (2006) in order to inform IMPRINT modelling conducted by Mr John Lockett of the Human Research and Engineering Directorate (HRED) of the Army Research Laboratory (ARL), Aberdeen, Maryland. Analyses of the 179 studies that satisfied criteria for inclusion in the study revealed that noise generally produces decrements in performance accuracy, but not speed of response. However, Hancock et al.'s meta-analysis also found that the effects of noise depended on the nature of the task. Noise had no impact on accuracy or speed of perceptual performance (i.e., visual discrimination), a small to moderate detrimental effect on accuracy of information processing and problem solving, a facilitatory effect on speed of information processing speed, and a medium detrimental effect on both speed and accuracy in numerical tasks. Although finding that noise appears to have a small to moderate impact on both fine motor continuous and discrete performance, Hancock et al. state this finding needs to be treated with caution due to the small number of studies involved.

Temporal characteristics of noise also determine the extent to which noise exposure affects performance. Research findings indicate that continuous noise is less disruptive than intermittent noise. However, both types of noise can disrupt performance on complex tasks as well as induce performance variability (Suter, 1989). Other considerations include findings that the novelty of a stimulus, irrespective of whether it's a change in noise characteristics or the onset/removal of noise, can disrupt performance (Suter, 1989). Even if performance is maintained, research has also found that this is at the cost of missing crucial social cues in the surrounding environment (Cohen & Lezak, 1977).

In an attempt to gain a clearer understanding of the impact of noise on performance, Ljungberg and Neely (2007) investigated the impact of noise and vibration individually and in combination on performance in cognitive tasks. They also measured subjective stress levels and salivary cortisol levels. Although subjective stress levels were higher when noise was present, participants' performance was not impaired and their cortisol levels did not reflect the subjective experience of stress. The finding that the presence of noise increased subjective stress, with no impact on performance, is consistent with a meta-analytical study that found that a moderate to large relationship between subjective stress and noise; but only a small relationship between noise and performance accuracy (Driskell, Mullen, Johnson, Hughes & Batchelor, 1992, cited in Salas et al., 1996).

The majority of research into the impact of noise on performance has been conducted in the laboratory environment. This research has indicated that noise of an annoying nature can: decrease working memory capacity, create perceptual and/or cognitive tunnelling, reduce the number of response options a person evaluates, and reduce a person's confidence that they can perform the task (e.g., reviews by Bourne & Yaroush, 2003; Hancock et al., 2006; Hockey, 1979; Salas et al., 1996). However, findings from the laboratory do not necessarily generalise to the work environment. For example, some research has found that workplace noise had no impact on speed or accuracy of performance (Kjellberg, Landström, Tesarz, Söderberg & Åkerlund, 1996). This

inconsistency may be due to workers in the latter having habituated to noise commonly occurring in their workplace.

On the other hand, other research has found workplace noise increased reaction time, impaired decision making, and degraded performance in an artillery simulator (see e.g., reviews by Bourne & Yaroush, 2003; Kjellberg, 1990). When one considers the inconsistency in research findings with respect to the impact of noise on performance, it is possible that even if a study found noise had no overall impact on performance, it may have created momentary lapses in performance that were masked or overlooked (Salas et al., 1996). In situations where such lapses might result in potentially catastrophic consequences, then noise arguably may have a large impact on performance (Cohen & Weinstein, 1981). This is particularly pertinent to the military environment where it is important to avoid fratricide and collateral damage.

Few studies measured physiological arousal when assessing the impact of noise on performance. A recent study evaluating the impact of moderate noise levels on the neuroendocrine system found that people with high noise sensitivity also had increased salivary cortisol levels. These people also had impaired performance on cognitively demanding tasks (Waye et al., 2002). However, there was no relationship between their subjective experience of stress and cortisol level. The lack of relationship between subjective stress measures and physiological responses in this study may indicate that measures are assessing different factors. Alternately, participants' assessments of their stress levels may have been contaminated by subconscious speed/accuracy trade-offs; or, as the authors suggest, individual differences in interpretations of the stress scale used. Moreover, the subjective feeling of distress does not generally appear to translate to a notable performance decrement (e.g., Driskell et al., 1992, cited in Salas et al., 1996; Ljungberg & Neely, 2007).

If a person is irritated by noise it increases their arousal level and, following the principle of the Yerkes-Dodson law, there comes a stage when performance deteriorates (Salas et al., 1996). There may also be a narrowing of attention so a person can focus on the task at hand, but at the cost of being potentially unaware of other important events around them and/or performance on other tasks (Bourne, & Yaroush, 2003). The arousal impact of noise on a person might also explain findings in which noise facilitated performance. If a person was fatigued prior to the study or as a consequence of task demands, then the arousal effect of noise might have had a compensatory effect on the person such that performance was restored. In other words, performance in the comparative condition with no noise may not have been optimal due to fatigue effects, and the addition of noise restored a state of equilibrium and optimal performance.

From a military perspective, studies indicate that noise does not impact on overall target detection, identification and marksmanship (e.g., Nakishima, Borland & Abel, 2007; Tikuisis & Keefe, 2007; Tikuisis, Ponikvar, Keefe & Abel, 2009) but it does affect communications (e.g., Nakishima, Borland & Abel, 2007). Moreover, if the task to be performed relies on the same modality as the noise (i.e., use of auditory information or verbalisation), then both the input (noise) and output require access to the same cognitive resources. This can create a potential confound between the auditory nature of both the

task and response and/or an increase in mental workload as resources are shared between analysis of the incoming noise and production of the verbal response.

#### *7.1.1.1 Summary and Military Implications*

It appears that the impact of noise on performance in the work environment depends on several factors. For example: the task itself, the physical characteristics of the noise (e.g., duration, volume, constancy, novelty), and psychological factors (e.g., whether a person perceives the noise as controllable, meaningful, and/or predictable) (Cohen & Weinstein, 1981; Saeki, Fuji, Yamaguchi & Harima, 2004). Nonetheless, it is suggested noise impacts on a person's performance by increasing arousal levels and/or distracting them (Salas et al., 1996). A general finding is that the impact of noise on performance is irregular, such that a person fluctuates between suboptimal and normal performance on a task (Salas et al., 1996).

General findings with respect to noise per se are that it increases general sensory arousal and narrowing of attention, has no effect on speed of performance, impairs working memory (Hancock et al., 2006), and reduces performance accuracy (Hancock et al., 2006; Salas et al., 1996). Ljungberg and Neely (2007) further identify studies that have demonstrated that noise can produce performance decrements in tasks requiring focused attention, memory performance, target detection, and mental arithmetic. Wilson et al. (2003) also identify that these decrements occur when people are exposed to noise that has high frequency and/or intensity or has low variability. There is also some indication that, even if noise does not affect performance while present, performance decrements are observed when the noise ceases (e.g., Suter, 1992)

Nonetheless, extant research into the effects of noise on performance is marred by possible confounds. For example:

- neurophysiological mechanisms and cognitive function may differ in their sensitivity to noise, however few studies gather physiological and cognitive measures
- there are individual differences in noise susceptibility but few studies investigate or control for these
- sound levels are not always measured, despite sound impacting on neurophysiological mechanisms, and by implication, cognition, in its own right
- habituation may alleviate the impact of noise on performance, however few studies identify the extent to which participants were habituated to environmental or experimental noise
- the better skilled a person is at a task the greater their automatic responding and the more resistant that task is to degradation as a result of noise exposure, yet individual skills are seldom considered
- there is no standardisation of the noise levels and/or frequency of the noise examined across studies

- it is unclear whether habituation effects are due to compensation through expenditure of effort, which can result in supra-optimal arousal. The longevity of the habituation effect should be explored.
- different tasks involve different cognitive processes and are underpinned by activation in different brain regions. Therefore studies need to manipulate complexity in a single task in order to identify the impact of noise on cognitive performance in simple and complex tasks
- studies usually examine performance at the end of a specified time period and overlook momentary lapses in performance
- a person's state of fatigue and/or sleepiness is seldom considered when investigating the impact of noise on performance, despite the fact that the arousing nature of noise may compensate for fatigue and/or sleepiness
- experiments using auditory tasks and verbal responses rely on the same modality and thus place demand on the same neural and cognitive resources.

The uncertainty of the effect of noise on performance is reflected in Table 7.1. Research to date indicates that noise increases arousal levels as well as perceptual and cognitive tunnelling. The impact on reaction time, accuracy, and target detection remains unclear. However, it impairs communication as well as performance on memory, decision making, reasoning, and vigilance tasks.

It is therefore important to gain a better understanding of the impact of noise on soldiers' performance on military tasks. Future research needs to address confounds present in previous research.

Military operations often occur in noisy environments that may affect psychomotor and/or cognitive processing important for military skills (e.g., marksmanship, situation awareness, navigation, decision-making, communications, vigilance). Further research is necessary to gain a better understanding of the impact of noise on soldier performance. This is particularly important given observations that personnel often do not wear hearing protection and, if they do, the efficacy of the protection in the field is much less than that observed in a laboratory (e.g., Suter, 1992). If the impacts of noise that have been identified are due to competition for the same cognitive resources, then this has implications for new technologies involving provision of information and/or decision support systems. Such a finding would suggest that technological aids (e.g., battle management systems, decision tools) need to allow the soldier to select between visual and auditory inputs depending on the work they are undertaking at any particular point of time. Research is also needed aimed at achieving a better understanding of the optimal means of information presentation for such aids as battle management systems and remote weapon stations within the battlefield context.

The potential impact of noise on performance also has implications for concepts aimed at reducing the load on the soldier. For example, the role of augmented cognition is for technology to interact with the soldier in such a way as to reduce the load on them.

Currently, work in this area is focused on understanding the issues involved; developing the technology that enables monitoring of a soldier's physiological and cognitive state; and developing systems that optimise the technology and soldier interaction. Algorithms used in augmented cognition should also consider noise characteristics and how they might affect performance.

The impact of intervening variables also needs to be examined. For example, noise has a disruptive effect on communication. Given the importance of communications in the military environment it is also important to determine situations where noise per se interferes with performance over and above the disruption due to impeded communication. Individual susceptibility to noise effects also needs to be further researched, particularly in the context of augmented technologies. Findings that some people are more affected than others indicates that any technological aid should not be designed as a "one size fits all". Rather, there should be sufficient flexibility in the design to accommodate individual variability. Research also needs to provide a more rigorous investigation of the interaction of task type, exposure duration, acclimatisation, individual differences, and the nature of the noise (decibel, frequency, continuous/intermittent).

Finally, the battlefield environment is complex and no one Input, such as noise, occurs in isolation. Soldiers are also exposed to Inputs such as thermal extremes, which may have a combinative nature. The impact of thermal extremes on performance will be summarized in the next section.

#### 7.1.2 Thermal Extremes

Unlike noise and vibration that occur on a continuum from none to extreme, temperature ranges from extreme cold to extreme heat. The impact of thermal extremes on physiological responses is well accepted: causing changes in heart rate, core temperature, skin temperature, and hydration (e.g., Amos et al., 1998). Also well understood is the impact on physiological capability (Bourne & Yaroush, 2003). However, the effect of thermal extremes on cognitive performance remains unclear. Moreover, there is a lack of consensus as to the optimal heat range for effective cognitive functioning. Even when researchers have undertaken a meta-analysis of studies using the internationally accepted Wet Bulb Globe Temperature (WBGT), the optimal ranges they identify differ (see e.g., Hancock et al., 2007; Johnson & Korbrick, 2001; Pilcher, Nadler & Busch, 2002). Nonetheless, the thermal range for optimal cognitive performance is likely to lie between 10 °C and 32.22 °C. Although these studies found that performance deteriorates at thermal extremes, they do not agree on the extent of the decrement. Nonetheless, if one accepts the lowest amount of observed decrement, then arguably performance declines by at least 11% at thermal extremes (see e.g., Hancock et al., 2007; Johnson & Korbrick, 2001; Pilcher, Nadler & Busch, 2002).

A major reason for the inconsistent findings is methodological differences in the studies. For example, different thermal scales are used (e.g., Centigrade, Fahrenheit, WBGT), and little attempt appears to be made to identify how the scale used in one study corresponds with other available scales. There are also differences in the exposure times to the different thermal conditions under consideration, the upper and lower limits people are exposed to,

and the tasks used to investigate the impact of thermal extremes on performance (see e.g., Gaoua, 2010; Hancock et al., 2007; Pilcher et al., 2002).

Despite findings that cognitive performance deteriorates at perceived optimal thermal extremes, the nature of the impact of thermal extremes on cognitive performance remains unclear. A general finding appears to be that cognitive, psychomotor and perceptual (e.g., vigilance, tracking) tasks are differentially affected by extreme cold and extreme heat. Nonetheless, Hocking, Lau, Silberstein, Roberts and Stough (2000) failed to find heat-related cognitive deficits. As a result of a meta-analysis of over 150 studies, Ramsey and Kwon (1992) state that there is little evidence of heat affecting performance on cognitive tasks.

Conversely, hyperthermia has been found to produce decrements in cognitive performance on complex memory tasks (e.g., Gaoua, Grantham, Girard and Racinais, 2010; Gaoua, Racinais, Grantham, & El Massioui, 2011; Racinais, Gaoua & Grantham, 2008). Hancock et al. (2007) found that extreme heat reduces performance accuracy for all cognitive tasks, but has no impact on reaction time. Bourne and Yaroush (2003) state there is some evidence that heat stress degrades performance on monitoring and auditory discrimination tasks, as well as working memory, information processing, and information retention. Similarly, with respect to military performance, Johnson and Kobrick (2001) identified that in hot climates performance on cognitive tasks (e.g., memory, decision making, mathematics) degrades at lower temperature than does performance on psychomotor tasks (e.g., manual dexterity, marksmanship). Thus, research findings range from no impact of extreme heat on cognitive performance through to decrements on all cognitive tasks.

With respect to psychomotor tasks, hyperthermia has been found to have no impact on performance of simple attention tasks (e.g., Gaoua, Grantham, Girard and Racinais, 2010; Gaoua, Racinais, Grantham, & El Massioui, 2011; Racinais, Gaoua & Grantham, 2008). Conversely, Ramsey and Kwon (1992) state perceptual tasks are markedly affected by extreme heat. Hancock et al. (2007) found that heat stress resulted in faster but less accurate performance on psychomotor tasks. Bourne and Yaroush (2003) identify there is some evidence that thermal stress degrades performance on psychomotor tasks, such as tracking. For psychomotor performance, research findings again range from no impact of extreme heat on performance to marked decrements.

To date, there is a dearth of research investigating the effect of extreme cold and/or hypothermia on performance. Amongst those studies that have looked at this, similar discrepancies exist as are present in the heat stress literature. For example, Hancock et al. (2007) found that cold stress resulted in slower but more accurate performance on psychomotor tasks. However, it increased speed of responding on cognitive tasks. Conversely, Castellani, Carter, Adam and Cheuvront (2009) found that cold stress had no impact on psychomotor or cognitive performance other than increasing reaction time on a sentry duty task. On the other hand, Bourne and Yaroush (2003) identify there is some evidence that extreme cold affects complex cognition. It has been suggested that extreme cold limits manipulation capabilities, thus affecting psychomotor performance; but it affects cognitive performance to a much less extent than does heat (Orasanu & Baker, 1996). Nonetheless, Hiatt and Rash (2011) state that extreme cold affects performance on

tasks requiring vigilance and/or decision-making, as well as on complex tasks. Lieberman, Castellani and Young (2009) also found that extreme cold decreased vigilance performance. Interestingly, Castellani et al. (2003) found that thermoregulation was disrupted in military personnel exposed to 84 hours of sustained operations. This suggests that cognitive decrements associated with exposure to extreme cold and/or hypothermia may reflect disruption of the circadian rhythms and increased sleep propensity due to a sustained decrease in core body temperature.

#### *7.1.2.1 Summary and Military Implications*

In summary, the effect of thermal extremes on cognitive performance remains unclear. It appears cognitive performance on simple tasks is maintained until the upper limit of the acceptable heat range, beyond which point it degrades. However, the upper limit depends on task complexity and cognitive demands (Hancock & Vasmatazidis, 2003). The Process Model of Stress and Performance may explain the failure to find any impact of heat on performance. For example, the heat exposure period may not have been long enough to challenge automatic adaptation mechanisms and consequently no decrement in cognitive performance was observed. Indeed, Hocking et al. (2000) argued that heat-related changes in brain activity were indicative of adaptive processes that allowed performance to be maintained. The thermoregulation changes observed by Castellani et al. (2003) are also indicative of adaptation. Gaoua et al. (2011) also argue that performance decrements observed in their study reflect hyperthermia-induced changes to brain activity. Similar arguments can be raised with respect to the effect of extreme cold on cognitive performance.

Nonetheless, extant research into the effects of thermal extremes on performance is marred by many confounds. For example:

- neurophysiological mechanisms and cognitive function differ in their sensitivity to thermal extremes, however few studies gather physiological and cognitive measures
- there are gender and individual differences in thermoregulation but few studies investigate or control for these
- hydration levels are not always measured, despite dehydration impacting on cognitive performance in its own right (Lieberman, 2007)
- sweat can affect performance either directly or indirectly as a consequence of equipment and/or clothing being dislodged (Johnson & Korbrick, 2001) and is seldom controlled for
- acclimatisation can alleviate the impact of heat on performance, however few studies identify the extent to which participants were acclimatised
- atmospheric phenomena (e.g., heat haze, mirage) can affect performance (Johnson & Korbrick, 2001) and is not controlled for

- the better skilled a person is at a task the greater their automatic responding and the more resistant that task is to degradation as a result of heat exposure, yet individual skills are seldom considered
- there is no standardisation of the temperature ranges examined
- exercise has been shown to improve cognition, yet many studies use exercise to induce hyperthermia, thus failure to find cognitive deficits may reflect the beneficial effects of exercise, rather than the impact of heat
- there is evidence that people can compensate for heat stress through expenditure of effort, which can result in supra-optimal arousal (Bourne & Yaroush, 2003). The longevity of this compensatory effect should be explored.
- different tasks involve different cognitive processes and are underpinned by activation in different brain regions. Therefore studies need to manipulate complexity in a single task in order to identify the impact of thermal extremes on cognitive performance in simple and complex tasks (Gaoua, 2010).

The uncertainty of the effect of thermal extremes on performance is reflected in Table 7.1. From research to date it is unclear what effect either heat or cold stress has on psychomotor and cognitive tasks.

Military operations often occur in thermal extremes, and such extremes may affect psychomotor and/or cognitive processing important for military skills (e.g., marksmanship, situation awareness, navigation, decision-making, communications, vigilance). It is therefore important to gain a better understanding of the impact of thermal extremes on soldiers' performance on military tasks. Gaoua (2010) and Hancock et al. (2007) correctly identify that future research needs to address confounds present in previous research. It also needs to provide a more rigorous investigation of the interaction of task type, exposure duration, acclimatisation, individual differences, and thermal intensity.

As with noise, thermal extremes do not occur in isolation. Other Inputs that may disrupt homeostasis and contribute to allostatic load are also present in thermal extremes. The next section summarises research with respect to the impact of motion on performance.

### 7.1.3 Motion

The ADF relies on rapidly deployable vehicles and it is envisaged that future manned platforms will have advanced command, control, communication and intelligence (C3I) capabilities. These vehicles are also likely to have advanced levels of automation aimed at reducing the workload on the vehicle occupants. However, the ADF is also currently considering reducing the number of crews in manned platforms. The advanced C3I and automation in these platforms will require performance of concurrent tasks ranging from simple vehicle control to complex decision making. The nature of operational threat in the asymmetric environment also means the ADF is increasing the physical protection offered

to vehicle occupants. This means that computerised systems will provide crew with vehicle control information as well as information from the external environment, with the latter being largely provided by one or more cameras.

Crew in manned vehicles are likely to be engaged in discrete and continuous manual tasks, as well as decision-making. With respect to manual tasks, research indicates that as the level of vibration increases movement control is degraded along with sensory input. Moreover, motion per se (of which vibration is a subset) affects reaction time and accuracy, such that increased motion is accompanied by reaction time increases and accuracy decreases. Sustained work in an enclosed vehicle also results in crew experiencing motion sickness and physical discomfort. The postural instability elicited by vibration can also impact on central nervous system processing, and thus impact on both physical and cognitive responses. (Metcalf, Davis, Tauson & McDowell, 2008).

Sensory information gained from our surroundings has redundancy that we use to interpret our environment. This additional information is likely to be missing for personnel in an enclosed vehicle and/or crew members who may be riding in one vehicle and controlling an unmanned vehicle or remote controlled weapon station. There is also a sensory mismatch arising from the speed of the moving vehicle and the speed of passing scenery. This sensory mismatch can degrade performance, as can insufficient environmental information (Metcalf et al., 2008). Thus, operation of unmanned vehicles and/or remote vehicle stations is likely to be compromised by the combination of the sensory mismatch related to motion per se and the lack of environmental information presented by the unmanned assets.

As Metcalfe et al. (2008) identify, the challenge is in ensuring optimal crew performance in moving vehicles in which crew are required to use advanced technology as well as performing their traditional roles. Motion characteristics alone are likely to produce decrements in cognitive, visual and psychomotor tasks. These decrements will be compounded by sustained periods of work in an enclosed vehicle and vehicle properties such as limitations on sensory information. Indeed, research into crew performance in military vehicles has indicated that a large amount of motion impacts on all tasks, with target acquisition and editing work being almost impossible (TARDEC, 2002).

Active suspension systems are being considered for use in military vehicles to minimise the vehicle vibration and enhance the ability to use vehicle computing systems whilst the vehicle is moving. However, although minimising vibration, adaptive suspension systems do not eliminate it completely. Nakashima and Cheung (2006) reviewed the literature to identify which vibration frequencies had the most impact on performance and concluded that vertical vibration around 5 Hz interferes with tracking performance and writing; visual acuity is affected by vibration between 2 - 20 Hz; whole body vibration (2-10 Hz vertical and <3 Hz horizontal) impacted on manual task performance; precise manual tasks (e.g., writing) were most affected by vibration frequencies of 4-6 Hz with errors increasing linearly with vibration magnitude.

These vibration frequencies are relevant to military vehicles. For example, Nakashima et al. (2007) found vertical vibrations present in the LAV III at 5 Hz in rough country and 2.5 Hz during highway driving. Decrement in visual performance have also been found in

studies conducted in a simulated vibrated environment, with frequency and magnitude of vibration reducing accuracy, increasing response time, and inducing fatigue (Lin, Hsieh, Chen & Chen, 2008). However, the impact of whole-body vibration on performance may be confounded by the impact of vibration on the equipment a soldier is trying to operate and/or read, consequently increasing an individual's cognitive workload during excessive periods of vibration (Merlo, Szalma & Hancock, 2008).

An important consideration is the design of the human-machine interface. For example, Metcalfe et al. (2008) found that, although data entry times were comparable when a vehicle was stationary or moving on smooth roads, when moving over rough terrain participants were quicker at entering target co-ordinates on a touch screen than they were with a trackball. Conversely, use of the trackball yielded greater data entry accuracy than did the touch screen. Thus, there is a speed/accuracy trade-off when deciding the means by which personnel will be required to enter data. Lin et al. (2008) further identify that vibration effects related to operation or reading of screens may be mitigated through increasing font size.

Crew interactions within a moving vehicle are important for mission success and it is therefore important to determine how motion impacts on team work within a vehicle, as well as between vehicles and command centres. The physical demands related to motion sickness and/or maintaining stability may interfere with cognitive resources needed for optimal performance at both the individual and team levels (Hill & Tauson, 2005). This is an area that needs further investigation, as does the impact on personnel required to perform military tasks on leaving a moving vehicle. The impact of motion on cognition is likely to take some time to resolve. However, there is evidence that exposure to whole body vibration enhances muscle performance in athletes (Fagnani, Giombini, Di Cesare, Pigozzi & Di Salvo, 2006). This would indicate that after being exposed to large amounts of motion, soldiers physical performance may be enhanced whereas their cognitive performance is diminished.

#### *7.1.3.1 Summary and Military Implications*

In summary, the advanced C3I and automation in manned platforms will change the manner in which crew perform their traditional tasks as well as exposing them to potentially large amounts of information. These effects may be compounded by a reduction in crew numbers. Research evidence indicates that personnel's capacity for optimal performance in moving vehicles will be compromised by motion characteristics, sustained work in enclosed environments, and reduction in sensory information. As Nakashima and Cheung (2006) identify, there has been little research on the effect of vibration in the horizontal axes, which are likely to be important for military personnel travelling in vehicles. Further, motion in military vehicles may include nauseogenic (nausea inducing) frequencies of <0.05 Hz (Nakashima & Cheung, 2006), and the impact of vibration on performance has been equated to that of a blood alcohol level of 0.08 (Cownings, Toscano, DeRoshia & Tauson, 2001).

Nonetheless, extant research into the effects of motion on performance is marred by many confounds. For example:

- neurophysiological mechanisms and cognitive function are both impacted by motion characteristics, placing a strain on physical and cognitive resources; however few studies gather physiological and cognitive measures
- vibration can impact thermoregulation in men, such that body cooling mechanisms are disrupted (Spaul et al., 1986), however, few studies identify the ambient temperature or consider the impact of vibration on thermoregulation
- technology within a moving vehicle is also likely to be impacted by motion; movements of such technology is likely to interfere with crew performance in its own right. Yet few studies investigate the individual and combined effects of having to work on non-static equipment and motion characteristics on human performance.
- atmospheric phenomena (e.g., heat haze, mirage) can affect performance (Johnson & Korbrick, 2001); the impact of this when sensory information is limited is not controlled for
- the better skilled a person is at a task the greater their automatic responding and the more resistant that task is to degradation; yet individual differences in working in moving vehicles are seldom considered
- different tasks involve different cognitive processes and are underpinned by activation in different brain regions. Therefore studies need to manipulate complexity in a single task in order to identify the impact of motion on cognitive performance in simple vehicle control and complex decision-making tasks.

The uncertainty of the effect of motion on performance is reflected in Table 7.1. From research to date it is unclear what effect motion has on psychomotor and cognitive tasks. Although researchers within LOD, DSTO Edinburgh have commenced a program of research aimed at increasing our understanding of the impact of vibration on cognitive performance, specifically with respect to utilisation of a battle management system (BMS) in a moving vehicle, much is still to be done. We still have limited understanding of the impact of vibration on tasks requiring attention, memory, situation awareness, decision-making etc., all of which are crucial for effective soldier performance.

Further research is necessary to ascertain the impact of motion on the ability of soldiers to perform required duties both whilst working in manned platforms and after being transported from one location to another. Moreover, as vibration in military vehicles may be nauseogenic, and interference with visual cues can induce nausea in its own right, it is important to investigate the effect of vehicles with visual restrictions on military personnel. Modern and future warfare increasingly relies on unmanned vehicles and remote weapon stations, which may be controlled by vehicle crew. Optimal control of such unmanned technologies is likely to be compromised by the reduction in sensory information, and mismatch in this information, afforded by both the vehicle and the unmanned technology. Future research needs to address confounds present in previous research. It also needs to provide a more rigorous investigation of the interaction of task type, exposure duration, motion characteristics, limitations in sensory information, ambient temperature, and individual differences.

### 7.1.4 Sleep Deprivation

Studies have shown that sleep deprivation has a similar impact on cognitive performance as intoxication (Dawson & Reid, 1997), with deficits identified in the cognitive skills essential for satisfactory performance of military tasks. It is well known that sleep deprivation has profound effects on cognitive performance. For example, it impacts on perception, attention, concentration, memory, motor skills, response time, accuracy, error rate, vigilance, decision-making, logical reasoning, moral judgment, visual performance, marksmanship skills, and emotions. Table 7.2 summarises key areas in which performance is affected by sleep deprivation and provides examples of papers addressing these key areas. With respect to decision making, it appears that decrements are due to a decline in complex decision making, where there is usually no correct solution and a person must consider a range of issues as well as a variety of options available to them; simple decision making remains relatively intact (e.g., Schnyer et al., 2009).

As well as affecting psychomotor and cognitive performance, sleep deprivation has been shown to produce deficits in moral judgment (Killgore et al., 2007) and emotions (Orzel-Gryglewska, 2010). Moreover sleep deprivation also compromises the immune system which is important for the physiological adaptation response to loss of homeostasis (Banks & Dinges, 2007; Miller et al., 2008), with increases in cortisol levels (Banks & Dinges, 2007; Leproult, Copinschi, Buxton & van Cauter, 1997) and other aspects of endocrine function (Meerlo, Koehl, van der Borgh & Turek, 2002; Spiegel, Leproult & Van Cauter, 1999).

*Table 7.2: Some critical soldier abilities and summary of research findings with respect to the impact of sleep deprivation on these; increase (+), decrease (-), no change (<>). Representative papers are also presented.*

Ability	Impact	Authors
Perception	-	Karni et al., 1994; Kavanagh, 2005; Kong, Soon & Chee, 2011; Orzel-Gryglewska, 2010; Quant, 1992
Attention	-	Banks & Dinges, 2007; Tomasi et al., 2009
Orienting	-	Martella, Csagrande & Lupianez, 2011;
Vigilance <sup>1</sup>	-	Lieberman, Tharion, Shukitt-Hale, Speckman & Tulley, 2002; Martella et al., 2011; Miller et al., 2008
Psychomotor skills <sup>2</sup>	-	Lieberman et al., 2002; Morgan, Doran, Steffian, Hazlett & Southwick, 2006; Helmus & Glenn, 2005; Nitsche et al., 2010
Reaction time	+	Belenky, 1997; Cain, Silva, Chang, Ronda & Duffy, 2011; Lieberman et al., 2002; Martella et al., 2011; Orzel-Gryglewska, 2010
Accuracy	-	Lieberman et al., 2002; Orzel-Gryglewska, 2010
Error rate	+	Cain et al., 2011; Lieberman et al., 2002; Orzel-Gryglewska, 2010
Concentration	-	Leonard, Fanning, Attwood & Buckley, 1998; Orzel-Gryglewska, 2010
Memory	-	Diekelmann & Born, 2010; Marshall, Helgadottir, Molle & Born, 2006; Morgan et al., 2006; Orzel-Gryglewska, 2010; Stickgold & Walker, 2005
Judgment/Decisions	-	Belenky, 1997; Harrison & Horne, 2000; Helmus & Glenn, 2005; Kavanagh, 2005; Orzel-Gryglewska, 2010; Schyner, Zithamova & Williams, 2009
Spatial Reasoning <sup>3</sup>	<>	Martella et al., 2011
Logical reasoning	-	Orzel-Gryglewska, 2010

<sup>1</sup>Sustained and focused attention (e.g., observations; radar)

<sup>2</sup>Coordination of physical and cognitive activities (e.g., marksmanship)

<sup>3</sup>Ability to form mental representations and manipulate these in the mind (e.g., navigation; identifying enemy/friendly locations)

As well as affecting psychomotor and cognitive performance, sleep deprivation has been shown to produce deficits in moral judgment (Killgore et al., 2007) and emotions (Orzel-Gryglewska, 2010). Moreover sleep deprivation also compromises the immune system which is important for the physiological adaptation response to loss of homeostasis (Banks & Dinges, 2007; Miller et al., 2008), with increases in cortisol levels (Banks & Dinges, 2007; Leproult, Copinschi, Buxton & van Cauter, 1997) and other aspects of endocrine function (Meerlo, Koehl, van der Borgh & Turek, 2002; Spiegel, Leproult & Van Cauter, 1999).

In general, the effects of sleep deprivation also appear to depend on the type of task with boring tasks being more vulnerable to disruption than interesting ones (Orasnu & Backer, 1996), and there will be individual differences in a person's perception of whether a task is interesting or boring. Orasnu and Backer further identify that the sleep deprivation associated with ConOPS and SUSOPS generally does not impact on physical performance, whereas cognitive tasks are affected, particularly the more complex ones. This is not inconsistent with their argument that interesting tasks are less affected than boring ones, as interesting tasks do not necessarily have to be complex in nature. Orasnu and Backer also identify that the cognitive decrement associated with sleep loss can occur as early as 18 hours after commencement of SUSOPS, with soldiers being ineffective after 48-72 hours of no sleep. In ConOPS, if soldiers receive less than 3 hours sleep per a 24-hour period, performance may only be sustained for several days. However, if sleep is increased to 4 hours or more, then performance may be able to be sustained for up to 2 weeks. Nonetheless, the nature of the performance that can be sustained and the extent to which it can be maintained remain unclear.

Because of its potential negative impact on performance, Defence organisations internationally promote sleep management plans to ensure personnel have sufficient sleep during operations. However, a recent study indicated that 80% of deployed American Army personnel received no instructions with respect to sleep management and, due to the large amount of time spent at high tempo, averaged about 4 hours sleep per night (Miller, Shattuck & Matsangas, 2011). These findings are consistent with those of a longitudinal study that found a large percentage of US military personnel are sleep deprived and fatigued, such that they sometimes fall asleep on duty (Miller, Matsangas & Kenney, in press). As Miller et al. (2011) identify, personnel are afforded physical means of protection (e.g., vehicles, clothing) but are exposed to danger as a consequence of sleep deprivation. After Action Reviews of American personnel involved in Operation Iraqi Freedom revealed an expectation by those personnel that fatal mishaps would occur as a result of fatigue and combat stress (Miller et al., 2008).

Recent evidence suggests that some people are more resilient to the effect of sleep deprivation than others (e.g., Rocklage, Maddox, Trujillo, & Schnyer, 2010). However, the biological reasons for this are still uncertain. Moreover, if there are individual differences in vulnerability to sleep loss, it raises several questions. For example, how long can these people work on sustained operations before their performance declines? Can they cope with high demand environments? Is their performance level comparable to others in the first place? Can these people be readily identified and utilised on sustained operations?

### 7.1.5 Fatigue

One of the major challenges is to differentiate between the concepts of sleepiness associated with sleep deprivation, and fatigue; as well as their respective impacts on performance. Although they are different concepts, their similarity in characteristics mean they are often conflated, both in the research literature and in popular use. Pigeon, Sateia and Ferguson (2003, cited in Shen et al., 2006) proposed that sleepiness should be used to describe a person's state characterised by drowsiness, decreased alertness, and sleep propensity; whereas fatigue should be used when referring to a state characterised by weariness, weakness, and depleted energy. It has also been suggested that fatigue does not necessarily need to be consequential to physical exhaustion (e.g., van der Linden, 2011). In other words, fatigue refers to a state on which a person feels that they lack the necessary resources to function effectively, but is not necessarily the result of sleep deprivation. Nonetheless, as Balkin and Wesensten (2011) identify, fatigue currently has no widely accepted definition.

As mentioned in Section 5, fatigue can be the consequence of sleep deprivation or task overload. Irrespective of the cause of fatigue, the consequences on cognitive performance are similar to those found after sleep deprivation. Reaction time slows and decision making is impaired (Schachter & Addis, 2010). Attentional lapses and/or a narrowing of attention occur, resulting in loss of situation awareness, inappropriate responding or responding to events that did not occur (Johnson, 2008; Westensen, Belenky & Balkin, 2005). Fatigue has also been found to contribute significantly to unauthorised weapon discharges both during preparation for and whilst on operations (Collyer, 2005), as well as friendly fire incidents (Westensen, Belenky et al., 2005). Further, despite the popular belief that fatigue – or sleepiness – may be counteracted by the flight-or-flight response, aviation studies have indicated that this is not always the case (Simon et al., 2010).

Studies of US Special Forces personnel during Survival Evasion, Resistance and Escape (SERE) training have indicated that extended exposure to disturbed sleep and extreme physical and psychological discomfort resulted in subjective feelings of fatigue, confusion and decreased vigour. Although it at first appeared that cognitive performance was unimpaired further investigation revealed performance deficits that were marked by an initial exertion of extra effort. However, although personnel could maintain performance for short periods of time this capacity was limited before performance declined markedly (see e.g., Harris, Hancock & Harris, 2005; Harris, Hancock & Morgan, 2005; Harris, Ross & Hancock, 2006). Findings from these studies indicate that personnel displayed deficits in logical reasoning, memory, and mathematical processing skills. In psychomotor tasks, reaction time increased, but with no loss in accuracy. This is not simply a speed/accuracy trade off, as in some tasks personnel were also slower when they were less accurate. Rather, it implies a general deterioration in performance, as opposed to a change in response strategy. Although performance in both simple and complex cognitive tasks was affected, simple reaction time tasks were more sensitive to a range of stress levels. Further, unlike for complex tasks (e.g., logical reasoning, memory), personnel were unable to compensate for poor performance by applying extra effort. This has implications for operational tasks such as sentry duty and marksmanship. Although SERE trainees expressed high subjective levels of fatigue, this did not predict cognitive performance

deficits. Instead, stress induced increases in reaction time were predicted by subjective evaluations of vigour and confusion (the ability to think clearly).

The findings and argument of Harris et al. (2005, 2006) are consistent with Selye's (1936) General Adaptation Syndrome, Hancock and Warm's (1989) Extended-U curve, Hancock et al.'s (2001) Process Model of Stress and Performance, and McEwen's description of allostatic load (1998). All of these argue adaptation processes allow retention of performance levels until the demand on resources is too great, at which time performance declines.

#### *7.1.5.1 Summary and Military Implications*

As identified above, the effects of sleep deprivation on both psychomotor and cognitive performance are profound. The seriousness of this is recognised by sleep management plans utilised by Defence organisations. However, there is evidence that these plans are not always adhered to, due to high operational tempo. Given the high potential for soldiers to compromise their performance efficacy, it is important that appropriate sleep hygiene plans be developed to minimise the likelihood of sleep deprivation.

Another critical area is the differentiation between the effects of sleep deprivation, as manifested by sleepiness, and those of fatigue. The former is a consequence of circadian rhythms that involve an irresistible need for sleep that must be met, if not temporarily addressed through pharmacological intervention (e.g., caffeine). Depending on the cause, fatigue may be overcome by a change of task, or it may be an indication of impending physiological or psychological exhaustion whereby a person reaches a state where they are no longer able to function. Because the obvious and hidden symptoms of fatigue will be same, irrespective of the cause, it is important to determine means of identifying when extreme decrement is imminent, as opposed to situations in which a simple change of task will suffice. Fatigue due to physiological exhaustion has implications for the military as this can result in lengthy loss of personnel through, for example, adrenal fatigue. One way to differentiate between sleepiness and the different types of fatigue is to assess neuroendocrine levels as physiological exhaustion disrupts these, whereas sleepiness can be assessed through sleep diaries and eye metrics.

Moreover, as Balkan and Wesensten (2011) identify, if we are unable to clearly delineate sleepiness and fatigue we are unable to identify their respective impact on performance. This means that in sustained or continuous operations we are unable to predict the impact of either concept on performance. In turn, this means we are unable to develop effective strategies to mitigate either sleepiness or fatigue so as to sustain and optimise performance. The confound between sleepiness and fatigue is reflected in Table 7.1, which displays similar research findings for these two concepts.

One of the major issues related to sleepiness and fatigue is that other potential stressors (Inputs) co-occur with them. This will be briefly touched on in section 7.6. The next section provides a very brief summary of the impact of protective clothing before moving on to examine the impact of psychological stressors on performance.

### 7.1.6 Protective Clothing

Although protecting personnel against weapon attacks and exposure to noxious agents, protective clothing such as CBA and CBRN can also impact on performance. To further increase soldiers' protection, defence forces are increasingly utilising encapsulation, which is "enclosing the soldier's body in such a manner that all skin is protected from exposure to the elements of the battlefield" (Mullins, Patton & Garrett, 2004). Body armour and Kevlar helmets have been identified as contributing factors in recent convoy accidents, due to their restrictions on perception (Johnson, 2008). Encapsulation has been shown to create claustrophobia in some people, (Garrett, Jarboe, Patton, & Mullins, 2006), as well as increasing heat strain and degrading weapon accuracy (Garrett et al., 2006; Johnson & Kobrick, 1997). Moreover encapsulation has been shown to produce decrements on tests of logical reasoning, spatial manipulation and addition after a cross country course simulating a dismounted warrior movement to contact mission (Mullins et al., 2004). For a variety of military exercises, encapsulation was also related to an increase in time taken to perform mobility tasks, decreased marksmanship accuracy, and subjective psychological distress (Garrett et al., 2006).

Chemical protective clothing was found to impair thermoregulation, resulting in electrolyte loss. It also restricted movement, and impaired manual dexterity, fine motor skills, marksmanship, accuracy and reaction times (Krueger & Banderet, 2009). Similarly, encapsulation provided by nuclear, biological and chemical (NBC) clothing markedly affected physical activity and thermoregulation in ADF personnel in hot climates (Amos & Gray, 1996). Thermoregulation is disrupted due to encapsulation limiting vapour transfer, and hence heat loss (Millard, 2004). This disruption in thermoregulation due to encapsulation results in similar performance deficits as seen in hyperthermia (see section 7.1.2 above).

Strategies to reduce disruption to thermoregulation include cooling of vehicle interiors (Millard, 2004) and incorporation of personal cooling technology in the protective clothing (Cheuvront, Montain, Stephenson & Sawaka, 2009). However, although providing some improvement in thermoregulation, these technologies are vulnerable to disruptions (e.g., loss of power supply). Cheuvront et al. (2009) have identified that biofeedback may be beneficial for enabling soldiers to maintain appropriate levels of skin temperature.

#### 7.1.6.1 Summary and Military Implications

In general, protective clothing has been shown to restrict soldiers' mobility and speed of performance. There is an increasing trend towards use of encapsulation. There is some evidence that encapsulation degrades performance on both psychomotor and cognitive tasks. From a military perspective, this has implications for factors such as marksmanship, speed of responding, situation awareness, and decision-making. The comparative paucity of research into the effects of encapsulation is reflected in the uncertainty in the impact of heat and clothing on performance (see Table 7.1). In extreme heat there may be cumulative affects on physical and cognitive performance arising from the disruption to thermoregulation due to ambient temperature and the additional load imposed by encapsulation.

### 7.1.7 Summary of the Impact of Physical Stressors on Performance

As identified in the preceding sections, although the impact of noise, thermal extremes, vibration, sleep deprivation, fatigue, and protective clothing on performance has been quite extensively researched, many uncertainties still remain. As can be seen from Table 7.1 many of these factors may impact on skills necessary for key military tasks such as marksmanship, situation awareness, vigilance, navigation, and decision-making. In some cases (e.g., thermal extremes, protective clothing, vibration, sleep deprivation fatigue) there is also a paucity of research with respect to their impact on cognitive performance relevant to tasks such as navigation, vigilance, decision-making, and identification of friend/foe locations.

There are also confounds in some areas. For example, are the impacts of vibration due to decrements in cognitive and/or psychomotor performance, or are they a consequence of equipment moving in its own right? Are effects of sleep deprivation due to sleepiness or fatigue? Are effects of protective clothing compounded by its impact on thermoregulation?

If we are to optimise military performance, further research is necessary with respect to the impact of these selected Inputs on performance.

## 7.2 Impact of Psychological Stressors on Performance

Although psychological factors other than mental workload can impact on performance (e.g., boredom, depression, having to kill someone), these are commonly addressed in the context of mental health issues. An interested reader wanting to more fully understand mental health issues is referred to references such as Bartone (1989, 1995, 2006, 2007), Delahaij et al. (2006), DOD (2000), FM 22-51 (1994), FM 6-22-5 (2000), Garbutt (2006), Helmus and Glenn (2005), and Kearney et al. (2004).

Consideration of factors pertinent to mental health issues is out of scope of this report, which focuses on the impact of select Inputs on performance (Output). This section summarises findings with respect to the effect of mental workload on performance as this has been the subject of intensive research.

### 7.2.1 Mental Workload

The modern soldier works in a complex, dynamic and ambiguous environment, and often at high tempo. Modern technology allows soldiers to be networked in a way they weren't in the past. Although such technology is aimed at enabling more rapid access to and integration of information (e.g., combined arms support, battle management systems), the technology can also increase the burden on the soldiers (e.g., Bakdash, 2012). This is due to the large amount of information that is potentially available to them. The various sources of information have to be integrated and used in a meaningful way, whilst in a demanding environment. Both the environment (including people within it) and technology present the soldier with information that they have to make sense of and respond to, often concurrently. Hence, both the environmental and technological demands draw upon a person's cognitive resources, potentially resulting in extreme mental workload.

If both sources of information utilise the same modality (e.g., visual, auditory, haptic) then they compete for scarce resources, creating a perception of strain within the person. Resource competition can also occur if a person is required to perform two or more demanding tasks, irrespective of the modalities involved. One reason for this is “cognitive tunnel vision” such that a person focuses their effort on the task they perceive to be of more immediate concern (Moray, 1993). Research has shown that this can have deleterious effects on performance on the ignored task. For example, Scribner and Harper (2001) undertook a study whereby soldiers were required to perform a primary shooting task requiring discrimination of friend or foe, as well as either a mental arithmetic or memory secondary task. The primary and secondary tasks were performed concurrently. Scribner and Harper found that although soldiers maintained performance on the shooting task, their performance deteriorated on the other tasks. Scribner and Harper argue this was due to them allocating resources to the shooting task. They further argue these findings indicate soldiers’ attentional resources may be stretched during battle. Depending on operational requirements at any point in time, they may therefore make errors with respect to friend/foe discrimination and/or overlook other crucial information in their environment.

However, as Oron-Gilad and Hancock (2008) identify, it is necessary to differentiate between task load and mental workload. The former refers to demand arising from the task itself, whereas the latter is the subjective evaluation of the impost of that task on the person. Burke, Szalma, Oron-Gilad, Duley and Hancock (2005) conducted a study similar to that of Scribner and Harper (2001), with the addition that they manipulated the task demands of the secondary memory recall task. Shooting performance was also assessed utilising a high fidelity simulator. Like Scribner and Harper (2001), Burke et al found that performance on the secondary tasks was affected by the shooting task. Interestingly, Burke et al. (2005) also found that soldiers performed better on the shooting task when the secondary memory task was difficult. This effect was absent for less demanding memory tasks. The reason for the facilitatory effect of the secondary task on shooting performance is unclear, but Burke et al. (2005) suggest it could be that participants found the memory task too difficult and focused mainly on the shooting task.

Sustaining mental effort consumes energy, with sustained effort resulting in fatigue and perceived strain on the human system. The more fatigued (physiological or mental) a person is, the more energy is required to sustain mental effort. More resources are also utilised by mental effort when a person is experiencing emotional upset, the task requires divided attention, new skills are required, and/or the task requires controlled processing (Gaillard, 2008). There is no direct relationship between task demands and mental effort as the latter depends on a person’s motivation to perform the task, the amount of energy they have available to do so, and whether they believe increased effort will improve task performance (Gaillard, 2008). Although some studies have found perceived increased task demands is related to performance decrements, others have not (e.g., Oron-Gilad, Szalma, Stafford & Hancock, 2008).

As Gaillard (2008) identifies, the precise mechanisms by which environmental and/or task demands affects performance remain a matter of debate. Nonetheless, Gaillard argues that being able to perform optimally when exposed to stressors depends on a person’s ability

to maintain an appropriate energy state and allocate attention to appropriate elements within the environment. This allocation of attention to relevant events can result in a narrowing of attention such that other potentially important information is overlooked, resulting, for example, in a loss of situation awareness. Alternately, attention may be momentarily distracted by extraneous information, such that performance on the task at hand suffers due to a person failing to detect critical information. This is known as inattention blindness (Mack & Rock, 1998). Paradoxically, inattention blindness can also occur when a person feels they do not have enough to do and therefore loses concentration (Mack & Rock, 1998).

There are also shortfalls in extant research. For example, military operations are likely to require personnel transitioning between high and low demand tasks. Nonetheless, much extant research focuses on performance related to either high or low demand (Oron-Gilad & Hancock, 2008). Thus, it fails to identify changing demands on cognitive resources and/or whether extra effort is required to make these transitions.

Moreover, the majority of research investigating mental workload occurs in controlled laboratory settings using tasks that are not directly relevant to the military environment. Nonetheless, it may be possible to extrapolate from research into driving accidents which is increasingly conducted in realistic settings. Although mental workload is assumed to impair driving ability, a causal link between increased mental workload and accidents is still to be adequately demonstrated (Brookhuis & de Waard, 2010). It remains to be seen whether similar findings are observed in naturalistic military environments.

Nonetheless, the impacts of mental workload on performance are similar to the impacts of sleep loss and/or fatigue. Stetz et al. (2007) identified that increased work demands impaired information processing such as perception, attention, vigilance, memory, and language as well as higher order cognitive processes involved in planning, SA and decision making. They suggest stress inoculation training via realistic simulations that allow people to acquire automatic responses to situations that disrupt homeostasis may mitigate the loss of equilibrium.

The similarity in the impact of mental workload and fatigue on performance highlights one of the major difficulties in evaluating the impact of stressors on performance. That is, that the concepts involved are often poorly defined. Difficulty in defining the concepts may be because they are referring to the same phenomenon and/or to phenomena that closely overlap. For example, fatigue has been conceptualised as a state whereby a person feels they lack the necessary resources to accomplish a task (e.g., Pigeon et al., 2003, cited in Shen et al., 2006). Similarly, mental workload has been conceptualised as a subjective perception that a task places too much burden on a person (e.g., Oron-Gilad & Hancock, 2008). In other words, it is requiring a greater effort than the person is capable of – or willing to – exert. If environmental or task requirements continue to be demanding for an extended period of time then a person may no longer be able to engage in the necessary adaptations to maintain optimal performance, and mental (or cognitive) fatigue is likely to occur; this in turn will limit a person's ability to respond to further environmental and task demands. In other words, they reach a state in which they, subjectively or objectively, lack the necessary cognitive resources to undertake a task. Mental fatigue can be chronic or acute (van der Linden, 2011). Due to its persistent effect on cognitive performance, chronic

fatigue (mental or physical) is arguably an indication of a severe disruption in homeostasis in which adaptation mechanisms are being stretched and a person may be approaching a dysfunctional state.

Acute fatigue, on the other hand, is of a comparatively short duration and related to task demands a person has faced throughout the day (van der Linden, 2011). Acute mental fatigue has been found to be related to workplace accidents. Some of these accidents may be due to people trying harder to maintain performance on one task, but at the cost of overlooking other important environmental cues or performance on another task (van der Linden, 2011).

#### *7.2.1.1 Summary and Military Implications*

Despite mental workload being identified as a potential stressor, there is still much we do not know about the mechanisms underlying the allocation of cognitive resources in complex environments requiring complex decisions and/or divided attention. Mental workload is itself a nebulous concept, which compounds the difficulty in measuring it. As Hancock and Szalma (2008) identify, more research is necessary to fully understand how stress affects information processing, the allocation of mental resources, as well as identifying factors that control allocation and use of mental resources. It was suggested in the preceding section that mental overload may be better conceptualised as mental fatigue, whereby a person is limited in the cognitive resources available to perform a required task. Such a definition might better enable our understanding of the impact of new technology on military performance in the operational environment. Irrespective of how we define the construct, research has indicated that tasks that are perceived to place a high demand on a person result in decrements in psychomotor skills as well as higher cognitive processes involved in situation awareness and decision making. As these processes are all necessary for effective military performance it is essential that research is conducted to investigate the impact of new technology and/or tactics, techniques, and procedures (TTP's) on the soldier. There also remains uncertainty about the impact of extreme physical exertion on cognition, particularly in a stressful and complex environment. This also needs investigation as the operational context inevitably requires soldiers to utilise psychomotor and cognitive skills on the move.

### **7.3 Impact of Pharmacological Interventions**

Defence organisations realise that sustained operations result in sleep loss for the soldiers, and that times when they are able to sleep may conflict with their circadian rhythms that determine the sleep architecture. These organisations are also cognisant that sleep deprivation impacts on physical and cognitive performance. Although physical activities are more resistant to the impact of sleep loss, when these require motivation or cognitive input they are more easily disrupted. Cognitive performance is more vulnerable to sleep deprivation, with less than 4 hours sleep over a 24 hour period resulting in rapid degradation on tasks requiring mental effort. Soldiers inevitably need to engage in sustained operations which may result in sleep deprivation. Some Defence organisations provide pharmacological aids to either promote sleep when it is possible, or sustain

arousal levels when it is not (see e.g., McLellan, Bell, Lieberman & Kamimori, Winter 2003-2004; Westcott, 2005). The pharmacologic agents used belong to two main categories: stimulants and sleep promoting drugs. It has been estimated that 12%-17% of American combat forces in the Middle East are using antidepressants or sleeping tablets to help them cope with operational demands (Rash et al., 2011). This section summarises the impact of the most commonly used pharmacological aids to maintain military performance.

### 7.3.1 Stimulants

The most commonly used stimulants are caffeine, modafinil and amphetamine (Caldwell & Caldwell, 2005; Wesensten, Killgore & Balkin, 2005). Sleep deprivation disrupts homeostasis by preventing the restorative process; thus adaptive mechanisms release hormones and chemicals that promote sleep onset. Stimulants counteract this effect through increasing hormones and chemicals associated with fight or flight, thus increasing arousal levels and hence alertness.

#### 7.3.1.1 *Caffeine*

Caffeine is not a controlled substance, and is readily available and widely used in society. It is available in various forms (e.g., as a drink, tablets, sweets, or chewing gum) and doses between 100-600mg have been found beneficial for maintaining performance during extended periods (up to 85 hours) of sleep deprivation (see e.g., McLellan et al, 2003; Wesensten et al., 2002; Wesensten, Killgore & Balkin, 2005). Specifically, caffeine has been shown to maintain wakefulness and improve fine motor control, attention, vigilance, reaction time, memory, and logical reasoning (Caldwell & Caldwell, 2005; McLellan et al., 2005; Roehrs & Roth, 2008). Caffeine also has a short half-life (i.e., it is eliminated quickly from the body), thus increasing a soldier's opportunity for obtaining sleep should the opportunity arise (Caldwell & Caldwell, 2005). It is unclear whether people develop a tolerance to the substance such that larger quantities of caffeine may be necessary to achieve the desired effect (Caldwell & Caldwell, 2005). For example, McLellan et al. (2003) found that the amount of caffeine regularly consumed did not affect its ability to counteract homeostatic disruption as result of sleep loss (McLellan et al., 2003). Conversely, other studies have found that, not only does tolerance occur, but caffeine withdrawal can promote rebound effects such as headache and sleepiness (Roehrs & Roth, 2008), as well as increasing anxiety and promoting hypervigilance (Caldwell & Caldwell, 2005). As a result of its arousal effects, caffeine can also create sleep disturbances (Alford, Bhatti, Leigh, Jamieson & Hindmarch, 1996). Nonetheless, caffeine has generally been found to enhance brain activity and counteract the effects of sleep deprivation and mental fatigue such that cognitive performance is improved (Lorist & Tops, 2003). Hence, the wide use of caffeine in Western societies.

#### 7.3.1.2 *Modafinil*

Modafinil is a psychostimulant with low addictive properties, and has been shown to improve wakefulness and cognitive performance during sleep deprivation associated with prolonged military operations. Like caffeine, it improves reaction time, memory, attention, vigilance, and logical reasoning (Caldwell & Caldwell, 2005; Westcott, 2005; Westensen et al., 2004; Westensen et al., 2005). Although it may also cause rebound headaches in some people (Wesensten et al., 2002), unlike caffeine, modafinil does not appear to create

rebound sleep effects (Caldwell & Caldwell, 2005). The exact mechanisms by which modafinil counteracts sleepiness associated with sleep deprivation is unclear. As modafinil appears to offer no benefit over caffeine with respect to maintaining wakefulness and improving cognition (Westensen et al, 2002), caffeine is suggested as the drug of choice. However, if it is likely that a person will have the opportunity to have a short sleep, then modafinil is recommended due to it not creating sleep difficulties (Caldwell & Caldwell, 2005; Westensen et al., 2002). It is unclear whether modafinil is utilised in military operations but (1) the studies reported here were undertaken in the context of military performance; and (2) it has been recommended for use by the United States Air Force when pilots are unable to sleep (Whitmore et al., 2004).

### 7.3.1.3 *Amphetamine*

The impact of amphetamine on performance in military operations has been well researched (Caldwell, Caldwell & Darlington, 2003). It is effective in maintaining wakefulness and improves reaction time and a range of cognitive functions including psychomotor performance and logical reasoning (Caldwell et al., 2003; Caldwell & Caldwell, 2005; Wesensten et al., 2005). Unlike caffeine and modafinil, amphetamine has been shown to be addictive (Caldwell et al., 2003). Findings that it may impact on selective attention (Westensen et al., 2005) also indicate that amphetamine should not be the drug of choice to overcome the effects of sleep deprivation.

## 7.3.2 Sleep Promoting Drugs

The most commonly used sleeping tablets in the Military environment are Temazepam, Zolpidem, and Zaleplon. These all work by activating chemicals involved in onset and maintenance of sleep. The Military environment is often not conducive to sleep onset (e.g., ambient noise, light, activities occurring around people); but because of their sleep inducing properties, these sleeping tablets can be beneficial when it is necessary to commence or restore sleep.

### 7.3.2.1 *Temazepam*

Temazepam has been used in military aviation for over 30 years and is particularly beneficial for counteracting the effect of disruptions to circadian rhythms, and enabling a person to sleep during the day when on night duty. It has a long half-life, meaning it is long acting and prevents arousals, and is therefore useful when a person has the opportunity to sleep for at least 8 hours. Nonetheless, the long half-life also means Temazepam may have residual effects such that a person experiences drowsiness and has decrements in psychomotor performance (Caldwell & Caldwell, 2005). Therefore, it is useful for promoting sleep when a person is chronically sleep deprived, their performance is markedly affected, and they would benefit from an extended period of sleep if the opportunity arises.

### 7.3.2.2 *Zolpidem*

Zolpidem has a shorter half-life (2-3 hours) than Temazepam and works within 15 minutes. It is therefore beneficial when a person is sleep deprived and has the opportunity for a few hours sleep. However, like Temazepam, it does impact on performance if woken too early (Caldwell & Caldwell, 2005). A United States Senate Enquiry in May 2010,

indicated that there is a “broad use” of sleeping medications and that many take Zolpidem (<http://www.cchrnt.org/2010/06/07/freedom-of-information-act-request-made-to-pentagon-officials-regarding-alarming-drug-overdoses-in-our-armed-forces/>). This is worrying, as newspaper reports in the United States have linked this sleeping tablet to road accidents. Moreover, anecdotal evidence from United States Military chat-rooms indicates Zolpidem has resulted in black-outs and memory loss, and that the drug is addictive.

#### 7.3.2.3 *Zaleplon*

Zaleplon has a shorter half-life (1 hour) than Temazepam and Zolpidem and is useful if personnel have the opportunity to have a nap of less than 2 hours. It is very good at sleep initiation and results in less residual drowsiness than either Temazepam or Zolpidem (Caldwell & Caldwell, 2005). It is unclear how widely Zaleplon is used within the military environment. However, Gray, Kenny and Pigeau (2003) found that melatonin did not degrade cognitive performance, as opposed to sleeping tablets, such as Zaleplon, and offered similar sleep benefits.

#### 7.3.2.4 *Melatonin*

Melatonin is a naturally occurring hormone that adjusts the body clock to reduce arousal and thus assist sleep. Like cortisol, melatonin is controlled by a circadian rhythm. However, melatonin and cortisol work in opposition. Melatonin concentrations within the body are low during the day and high in the evening; cortisol levels are low during the night and rise in the morning. Although the relationship between melatonin and cortisol is poorly understood, studies indicate that the increased cortisol production associated with stress can disrupt sleep due to increased cortisol levels interfering with melatonin's circadian rhythm (see e.g., Monteleone, Fuschini, Nolfé & Maj, 1992). Although research has indicated that melatonin may improve memory function during stress (e.g., Rimmelé et al., 2009), this may be due to its sleep enhancing properties and the role sleep plays in memory consolidation.

### 7.3.3 Combined Use of Stimulants and Sleeping Tablets

As sustained operations require soldiers to perform effectively for extended periods, yet the deleterious effects of sleep deprivation need to be counteracted, it is desirable that personnel can sleep when an opportunity arises. Recent work has investigated the efficacy of administering medication that combines stimulants with sleeping tablets. Slow release caffeine combined with Zolpidem was found to maintain performance for 18 hours as well as improving sleep quality (Beaumont et al., 2001). Similarly, use of Zolpidem to promote sleep, followed by either caffeine or modafinil, enhanced performance during extended work shifts (Batejat et al., 2006). Nonetheless, Meijer and de Vries (2006) argue that research so far is based on limited samples and we still not know whether pharmacological aids do in fact improve performance. Moreover, they identify that, just as person who has had too much alcohol cannot identify they are drunk, a person who is fatigued cannot identify that they are fatigued. They state that if we are to be able to identify whether pharmacological aids improve objective performance, as opposed to simply subjective performance, well conducted field trials are necessary in which people are randomly allocated to non-drug and drug conditions. It is unclear the extent to which

stimulants and sleeping tablets are being prescribed within the military. However, the aforementioned United States Senate Enquiry indicates that drug mixes are being prescribed to a reasonable percentage of the military deployed to the Middle East. Figures with respect to Australian Defence personnel are unavailable but one assumes that those personnel deploying with United States troops and under their command are likely to have access to the same medications.

#### 7.3.4 Summary and Military Implications

Although the use of stimulants and sleep inducing drugs has been beneficial in alleviating the effects of sleep deprivation, pharmacological substances do have impacts on performance. The optimal solution would be adequate staffing and appropriate work-rest schedules that remove the need for sustained operations over extended periods of time. There is recognition within the area of sleep medicine that long term use of sleeping tablets can result in addictions and these also alter the sleep architecture, specifically presence and duration of REM and NREM sleep. As these respectively have memory/skill enhancing and restorative roles it is necessary to understand the consequences of the long-term interference with these sleep stages. Moreover, as Selye's (1936) General Adaptation System and McEwen's description of allostatic load indicate, there comes a stage when the body can no longer cope with the demands of the adaptation mechanisms invoked to restore homeostasis. As pharmacological interventions are themselves creating responses within the neuroendocrine underpinning the physiological adaptations, the question arises as to the long-term consequences of continuous interruptions to this system.

Moreover, there could be behavioural measures that counteract the effects of fatigue. For example, recent studies (Ariga & Lleras, 2011; Pattyn, Neyt, Henderickx & Soetens, 2008) have found that vigilance decrements were due to habituation and boredom, rather than declining attentional resources in memory or cuing tasks. Participants who were required to interrupt the vigilance task on rare occasions and perform a brief task displayed increased performance on a vigilance task (Ariga & Lleras, 2011). The implications of this for the military are that if there are opportunities for occasional tasks to be interspersed with ongoing activities (e.g., vigilance), this may restore performance levels. However, although being able to occasionally switch tasks may be useful for alert people, it is a matter for research whether the same benefit would apply following sleep deprivation.

Finally, recent research also suggests that some people are naturally more resilient to sleep deprivation than are others (Van Dongen & Belenky, 2009). Identification of such people within the military population with the appropriate skill levels, could negate (or reduce) the need for deploying vulnerable personnel to sustained operations.

### 7.4 Impact of Resilience Training

Whilst traditional military training is still useful for imbuing skills, drills and procedures essential for the operating environment, there is recognition that this training does not prepare people for the diverse environmental and task demands they might face and which might disrupt homeostasis. Traditional training promotes automatic responding, which requires fewer resources and therefore reduces likelihood of change in homeostasis.

However, the dominant response (automatic or preferred response) may not always be the correct one (Delahaij et al., 2006). As mentioned in Section 6, the aim of resilience training (sometimes referred to as stress inoculation training, stress exposure training, or hardiness training) is to provide people with the necessary skills and adaptive responses to withstand a variety of environmental and task demands. There is evidence that this type of training improves the mental health of military personnel as well as improving performance (Stetz et al., 2007).

There is also a recognised need for military personnel to be trained in realistic environments in which they are exposed to a diverse range of events and conditions (e.g., sleep deprivation, thermal extremes) that potentially disrupt homeostasis. When faced with an extreme situation on military operations, soldiers usually resort to the dominant, well-trained response. This dominant response utilises fewer physiological and cognitive resources and thus reduces the likelihood of loss of homeostasis. Training in a diverse range of realistic and demanding environments will increase the range of dominant responses available and thus maximise the likelihood that not only will these be used but the correct response will be used (e.g., Mackey, 2008).

Bartone (1989, 1995) developed a measure of resilience that is being internationally adopted (Bartone et al., 2006): Dispositional Resilience Scale – DRS; the latest version is the DRS15-R. People showing high levels of resilience report they are less affected by environmental and task demands than are people with low levels of resilience (Bartone, 2007). Resilient individuals are also better prepared to cope with demanding and distressful situations, evidenced by better performance than those displaying low levels of resilience (Maddi, 2007). Individuals with high coping skills display differences in the amount of hormones and autonomic nervous system activation present in the homeostatic state (e.g., Feder, Charney & Collins, 2011). This may dispose them to handle adverse situations that potentially threaten homeostasis better than other people do. Although in its infancy, research into factors underlying resilience has identified that personality, coping styles, belief in one's own ability (e. g., Kavanagh, 2005), and the way in which challenges are perceived might all impact on a person's level of resilience.

Emotional intelligence, which is the ability to comprehend factors related to one's own emotions as well as those of others, has also been linked to resilience (e.g., Ashkanasy, Aston-James, & Jordan. 2004). Some of the approaches in resilience training are based on the relatively new area of positive psychology that argues people can change the way they perceive and react to adversity to minimise threats to homeostasis (e.g., Seligman & Csikszentmihalyi, 2000).

#### 7.4.1 Summary and Military Implications

Resilience training can enhance the adaptation process by changing the way people respond to potentially adverse events, thus reducing the demands on resources by physiological and psychological adaptation responses. As Maddi (2007) identifies, soldiers could benefit from resilience training. Soldiers regularly train in environments that emulate the potential operational environment. However, if they are also trained to alter their perceptions of the nature of the environment then they are less likely to be adversely affected by Inputs that would usually disrupt their homeostatic state. For example, as well

as training to perform their military tasks in adverse environments, soldiers can also be trained to believe that they are capable of operating effectively in such environments. The belief that they are capable of performing well under adversity and can adapt well, will better prepare them for the operational environment. Moreover, those naturally high on resilience could be selected for especially demanding tasks. Although there is some evidence that training soldiers in a wide range of unpredictable environments, does allow them to engage in automatic responding in the operational context (e.g., Driskell et al., 2008), this may not always be the case (Ross, Szalma & Hancock, 2004). The field of resilience training is relatively new. Although it is being utilised within the Australian Defence Force, there is a paucity of research evaluating the effectiveness of resilience training on soldiers deploying on operations. More research is necessary to fully understand its effectiveness at preventing, or minimising, disruption of homeostasis.

## **7.5 Impact of Augmented Cognition**

The field of augmented cognition is still in its infancy, as are the associated areas of neuroergonomics and adaptive automation upon which it draws. The former seeks to apply principles of the cognitive neurosciences and ergonomics to enhance our understanding of human behaviour. A central feature of adaptive automation is the appropriate allocation of tasks and/or task components between technology and the human to maximise performance outcomes. Similar principles are involved in brain machine interface research focused on devising means by which humans can directly control technology via their brain activity.

The aim of augmented cognition is to reduce the burden on the soldier by having technological aids that behave in a biologically plausible fashion and thus enhance and/or complement the soldier's capabilities. This is achieved through identification of a person's psychophysiological state and communicating it to the technology such that (a) the technology can sense when the human is fatigued and/or mentally overloaded and it needs to intervene; (b) the human can identify when they are overloaded and need to pass control of some task – or task aspects – to the technology; (c) humans and technology can interact as a team – for example, combined human-robot teams; and (d) a commander in the field can monitor the physical and mental state of a soldier and identify when they need to be replaced and/or select the best person to fulfil a particular mission at a certain point in time.

Robotics and remote controlled weapon stations are examples of areas in which adaptive automation might be used to reduce the impost placed on the operator of such equipment. The ultimate objective of augmented cognition programs is the seamless interaction of humans and technology so as to improve soldier performance. This is achieved through monitoring soldier performance and intervening when the soldier is cognitively or behaviourally at risk.

Although rapid advances have been made with respect to appropriate metrics and technology for monitoring of soldier performance, research is still necessary to identify the most appropriate and relatively unobtrusive technologies. Research is also needed to identify suitable algorithms to identify when a soldier is becoming overwhelmed by

environmental and task demands. Key research questions in this regard relate to the amount of autonomy that can safely be imbued in the technology (such as robotics and unmanned vehicles); identification of optimal means of sharing of control between humans and technology; and ways in which neurophysiological mechanisms might be used to facilitate the human-technology interactions. Such research will complement advances in adaptive command support systems designed to tailor information for the warfighter.

Although the concept of augmented cognition may seem futuristic, some of the technology is already in use. For example, some modern motor vehicles detect when a person is sleepy and take intervention measures so the person does not drive whilst asleep. One of the major areas hampering progress in adaptive automation is the lack of portable and reliable physiological metrics.

## **7.6 Interaction Effects**

Military operations are complex, dynamic, ambiguous, high tempo, and personnel are often sleep deprived and subjected to large amounts of information. Thus, they are simultaneously exposed to several factors that threaten homeostasis. As mentioned when summarising the effect of selected Inputs on performance, none of these Inputs exist in isolation. Thus, their impact on performance in the operational setting is less clear. Although an important consideration, the interaction of stressors has not been extensively researched. This section summarises some of the extant knowledge in this area.

### **7.6.1 Sustained Operations and Cognitive Demand**

As Military personnel are often engaged in high tempo operations involving threat and/or danger for extended periods of time, it is important to identify factors that impact on their ability to sustain satisfactory performance on required tasks during this time. Some researchers (e.g., Harris, Hancock & Harris, 2005) have investigated cognitive changes related to changes in homeostasis as a result of a week's SERE training. Harris et al. found SERE participants reported subjective discomfort and fatigue, as well as displaying decrements in their ability to manipulate information, respond quickly, and reason logically. Although participants' performance at the beginning of any of the cognitive tests used was satisfactory, it rapidly deteriorated. Harris et al. argue this may reflect that the adaptation process that allowed them to continue with the SERE training may have continued for the initial stages of cognitive testing but their resources rapidly declined; hence the overall performance deteriorations.

These findings have implications for soldiers' ability to undertake complex decision making activities following extended periods of demanding military operations. Lieberman, Niro et al. (2006) conducted a similar study utilising a simulated sustained operation scenario in a laboratory environment. Participants undertook a variety of activities over an 84 hour period (e.g., road march, battle drills, confidence course, set up a command post, and physical training) during which sleep was restricted to be equivalent to that which personnel would have during sustained operations. They found that soldiers' performance deteriorated over the course of the 84 hours in much the same way

as they did during field exercises; specifically, well learned tasks such as marksmanship and physical performance were unaffected. However, participants displayed marked performance decrements with respect to vigilance, memory, and attention and response time for detection and response to simple stimuli was increased. Both studies identified that performance was initially maintained and then deteriorated when people participated in sustained operations during which they experienced many factors that potentially resulted in allostatic overload. More importantly, both of these studies involved more than one Input. For example, sleep deprivation, physical exertion, and multiple tasks. Many studies investigating the effectiveness of new technology are carried out with soldiers performing tasks they would normally undertake when utilising such equipment. The question arises, however, as to how many of these studies also emulate the sleep deprivation, thermal extremes, noise etc. that may be present in the operational environment in which the equipment will be used.

### 7.6.2 Physiological Adaptation Responses and Cognitive Demands

Both mental workload and physical environmental demands have been shown to affect the endocrine and autonomic nervous systems, with an increase in cortisol levels (Lean, Shan, Xuemei & Xiaojian, 2011). Although finding changes in brain activity related to reading comprehension and mental arithmetic, they did not find increases in salivary cortisol levels and argue this could reflect other factors (e.g., optimism) that might reduce cortisol levels. An alternate explanation is that the laboratory setting may have disrupted homeostasis sufficiently for brain activity to reflect adaptation processes, but the duration of the study was insufficient to elicit a noticeable increase in cortisol levels. As identified in section 6.1.1.1, cortisol is implicated in glucose regulation as well as turning off the fight-or-flight response.

#### 7.6.2.1 *Physiological adaptation, physical exertion, and cognitive demands*

Taverniers, van Ruysseveldt, Smeets and von Grumbkow (2010) investigated performance and physiological markers while Belgian Special Forces candidates were undertaking a strenuous mock prisoner of war exercise. They found that, compared to a condition designed not to threaten homeostasis, the prisoner of war exercise was associated with increased cortisol levels, decreased performance on tasks relevant to identification of map co-ordinates, memorisation and reporting of a target location, as well as increased subjective workload measures. Moreover, unlike in laboratory studies, there was a direct relationship between cortisol levels and subjective workload measures, but the reason for this relationship is unclear.

There is an imperfect correlation between subjective, objective and performance measures (Orasnu & Backer, 2006), for which they argue there are at least three explanations: physiological effects precede subjective feelings; the subjective feeling precedes performance impairments; physiological, subjective and performance measures are independent and assess different phenomena. Although the reason for the imperfect correlation between these measures is currently unclear, a solution may be found in the Process Model of Stress and Performance (Hancock et al., 2001), that identifies many of the adaptive mechanisms to stress are automatic. However, at some stage these automatic responses are unable to maintain homeostasis and conscious effort is required to allocate

physical and cognitive resources necessary to perform a required task. Conscious awareness of resource demands would be necessary for a person to make a subjective judgment that they are experiencing a large task demand. Conversely, physiological responses may occur automatically and impact on subsequent performance independent of subjective evaluation.

Nonetheless, as participants in their study were exposed to both physical and cognitive demands, Taverniers et al. (2010) illustrate how physical exertion and cognitive load can interact to produce potentially cumulative threats to homeostasis, with a loss of automatic adaptive responding and an associated demand on cognitive resources. Research to date generally indicates that physical exertion facilitates cognition, possibly due to its arousal effect (e.g., Krausman, Crowell, & Wilson, 2002). However, these studies generally do not examine cognitive performance during prolonged physical exertion. Further, there is also evidence that cognitive effort can also impact on physical performance (Marcora, Staiano & Manning, 2009; Millet, Divert, Banizette & Morin, 2010). Because soldiers are increasingly exposed to large amounts of information that they need to evaluate on the move, it is important to more fully understand the combined effect of physical exertion and cognitive demands.

#### 7.6.3 Thermal Extremes, Equipment, and Performance

Other studies have indicated that production of sweat as a result of heat exposure can interfere with visual tasks, and vibration can interfere with performance due to distortion of a visual display (Hancock & Weaver, 2003). With respect to sweat, if a task relates to use of head mounted displays or night vision goggles, any impact of these on visibility is likely to be confounded by the impact of sweat, irrespective of whether the latter is due to factors such as extreme heat and/or encapsulation. This further highlights the need to consider the potential operational environment when evaluating new technology and/or clothing and other equipment. Indeed, Hiatt and Rash (2011) argue that evaluation of any advanced display concept should include consideration of a multitude of factors, including: environmental (thermal, obscurants, rain, sunlight); mechanical (vibration, eyewear, interface with other equipment); physiological (fatigue, sleep deprivation, hypoxia, medical condition, physiological state such as hydration, pharmacological use); sensory (glare, illumination, luminance, noise); and psychological (mental state, emotional state, fear, anxiety, workload).

#### 7.6.4 Vibration, Physiological Adaptation, and Performance

A further example of interaction effects is that vibration at frequencies above 1Hz can activate the endocrine and autonomic nervous systems in its own right and disrupt homeostasis. For example, vibration can impact on balance, and has also been shown to interact with noise and hyperthermia (Previc, 2004). Thus, when examining the impact of vibration on performance, physiological responses of vibration alone need to be considered and controlled for.

#### 7.6.5 Sleep Deprivation, Physiological Adaptation, and Performance

Short term sleep deprivation prevents restorative processes, increases body temperature, and increases activation of the endocrine and autonomic nervous systems involved in the

General Adaptation Response. The increased body temperature makes it increasingly harder for a person to go to sleep. Thus, continued sleep loss interferes with a person's ability to restore homeostasis. This would mean a person becomes aware of their sleep-deprived state, resulting in competition for attentional resources and potential performance decrements if a cognitive task requires deliberate effort. When considering the impact of heat extremes on performance, potential physiological changes due to sleep deprivation should also be considered.

#### 7.6.6 Noise, Heat, and Performance

Studies have also indicated that noise effects interact with heat. In heat conditions present in the normal office environment, the impact of low and moderate noise volumes on memory tasks is comparable. However, in a hotter environment, memory performance is better at lower noise levels than it is at high noise levels (Hygge & Knez, 2001).

#### 7.6.7 Heat, Equipment, and Performance

Apart from directly impacting on performance, hot environments can interact with equipment and disrupt performance. For example, build up of condensation on goggles and windscreens can interfere with vision (Johnson & Kobrick, 2001). Wearing protective clothing can also interact with psychological factors to compound its effect on performance. For example, they can cause claustrophobia, decreased vision, respiratory distress, and a sense of isolation (Stokes & Banderet, 2009). Training in thermal extremes have helped soldiers acclimatise to the likely operational environment and therefore reduced the impact of thermal extremes on cognitive responses (see e.g., Johnson & Kobrick, 2001; Radakovic et al., 2007). Training in protective clothing will have the same effect (Stokes & Banderet, 2009).

#### 7.6.8 Resilience Training, Adaptation, and Performance

Arousal and stress interact, as to some extent arousal mediates the impact of stress. If a person is under-aroused then light stress facilitates performance. But stress can induce abnormally high levels of arousal leading to impaired performance. For a short period, the effects of stress can be counteracted through increased effort, and mobilisation of cognitive resources. The latter involves use of conscious strategies that control effort expenditure allowing a person to adapt to task demands or the source of stress. However, maintenance of performance in this way comes at a cost. A person perceives they are expending more effort on the task and/or there is an accompanying excessive occurrence of allostatic processes.

#### 7.6.9 Time pressure and Mental Workload

The time available to perform one or more tasks and the cognitive resources a person believes they have to perform these interact. To optimise their use of resources within the time available, a person will prioritise tasks, or subcomponents of a complex task. This prioritisation may occur consciously or subconsciously. Many studies investigating the effect of mental workload on performance also involve time pressure as they limit time available to perform the task. In the operational environment, a soldier is likely to be faced with several instances when they have to respond under time pressure. If one wants to

mitigate against errors that may arise in this situation, it is necessary to better understand the interaction between time pressure and mental workload and how this impacts on soldier performance.

#### 7.6.10 Summary and Military Implications

As Nikolova and Collins (2003) experienced, it is difficult to disentangle the effects of physical and psychological Inputs on performance. Nonetheless, if one wishes to develop strategies that mitigate the impact of specific Inputs on military performance then it is important to identify ways in which the individual Inputs effect performance, as well as the manner in which they interact with each other. For example, military personnel are unlikely to utilise new technology in the absence of other environmental and task demands. The aim of new technology is to improve soldier performance in military operations, irrespective of the nature of these operations. Thus, personnel will be using the technology in a demanding environment in which they may be sleep deprived and required to achieve optimal physical and cognitive performance when exposed to factors such as thermal extremes, noise and/or vibration. The question arises, what is the impact of the new technology in different combinations of these Inputs. Are their effects additive or cumulative? Will one mitigation strategy work for all combinations?

## 8. Overview of Metrics

When evaluating the impact of stressors (Inputs) on performance (Output), it is necessary to identify the Inputs of interest given a particular research question. The Inputs to be considered would include:

- Environmental factors (e.g., thermal, noise, lighting, visibility, altitude, vibration); and
- Task demands (e.g., simple or complex task, temporal demands).

It is also important to consider mediating factors that would enable/hinder a person's performance. These would include:

- Personality
- Coping style
- Emotional intelligence
- Skill level.

To ensure that the right performance metric is used, it is important to consider the nature of the task, the skills involved, and cognitive processes likely to be used. Output measures would therefore involve consideration of factors such as:

- whether the task involves psychomotor and/or cognitive processes
- the type of psychomotor processes involved (e.g., perception, manipulation)

- the nature of cognitive processes involved (e.g., attention, working memory, long term memory, decision-making).

To determine the impact of Inputs on Outputs, it is also necessary to identify the current state of the Input (e.g., thermal temperature, visibility, task demands) and/or to develop different levels of the Input of interest. For example, if one is interested in whether a soldier can utilise new technology in thermal extremes then the thermal extreme of interest needs to be identified, as well as suitable comparative temperatures that can be used for a baseline. In experimental terms, this equates to creating different levels of the independent variable, the factor predicted to elicit a change in performance. Thus, in experimentation, the Input becomes an independent variable.

There are a range of measures available to evaluate Inputs of interest to the military. This paper is not going to comment on the individual tools available. The important point is that the appropriate measure is selected to address the research question. For example, if looking at thermal extremes, one could use the WBGT or an alternate metric. The researcher will select the metric and justify their decision. Alternately, they may choose to use more than one metric for the same phenomenon.

To more fully understand the impact of Inputs on Outputs it is also important to measure physiological indicators of adaptation where this is possible. One way to do this is through measurement of physiological responses, such as heart rate variables, brain activity, respiration, eye activity, and neuroendocrine levels. In some cases it would also be appropriate to measure psychological factors (e.g., learning effects), as these may impact on performance.

As well as adaptation mechanisms, it is also important to assess potential moderating variables so the impact of these on the relationship between Input and Output can be controlled. This will require using metrics evaluating factors such as skill levels, self-efficacy, personality, and confidence.

With respect to measurement of Outputs, the research question should determine the performance(s) of interest. Relevant metrics would include those assessing psychomotor performance and/or cognitive processing. Depending on the question being addressed, it may also be appropriate to measure psycho-physiological responses. As well as being a correlate of adaptation, some psycho-physiological metrics can also be a measure of performance (e.g., changes in eye pupil diameter and brain activity have been related to cognitive workload).

As with measurement of Inputs, there is a diverse range of metrics available to assess performance. The researcher will need to determine the metric that is appropriate for answering their research question. Moreover, if soldiers are to be engaged in the study, metrics chosen will need to be readily identifiable as relating to military performance. The same argument applies to tasks used to assess the impact of Inputs on Outputs.

The aspirations of the growing field of augmented cognition include the monitoring of soldiers' performance in the field. Before this field can reach maturity, appropriate metrics and technology are needed to record, analyse, and display physiological and cognitive

measures. Rapid advances have been made in this area. For example, technologies exist that enable monitoring of the operator functional state through identification of vigilance levels or changes in brain activity. With respect to the former, Lieberman, Kramer, Mountain, Niro and Young (2005) from Natick have developed a vigilance monitor, based on an actigraph. This monitor is worn on the wrist and records ambient noise, temperature and humidity, a person's responses (e.g., vigilance, reaction times) to stimuli, as well as arousal levels. It can also be used to generate auditory, visual, and vibratory stimuli. Researchers such as Davis, Popovic, Johnson, Berka & Mitrovic (2009) have developed advanced technologies that enable recording of brain waves whilst soldiers are performing military activities. This allows identification of not only soldiers' vigilance but also changes in their resource capacity for performing a range of military tasks. Major challenges in these areas are not only development of the appropriate technology, but also suitable algorithms for measuring mental workload.

A key factor with respect to metrics is that the disparity in extant research methods makes it difficult to consolidate findings with respect to the impact of environmental and task demands on performance. It is important that researchers utilise common methods so findings from different studies can be compared and evaluated. This is aspirational and difficult to achieve in a short period of time within the broader research community. Nonetheless, it could be achievable within DSTO. The following recommendations are therefore made with respect to metrics used within DSTO:

- For thermal extremes, it is recommended that the WBGT be used as this is an internationally recognised index.
- For motion (including vibration), direction, speed, terrain type, roll, pitch and heave measures should be obtained.
- For performance, soldiers' capacity for conducting normal activities (e.g., march, obstacle course, navigation, marksmanship, vigilance) should be evaluated. This is because it is their ability to perform required duties whilst on operations that is at stake. However, when this is impractical, tests utilised should map onto these military tasks.
- Where appropriate, other measures such as response time, accuracy, logical reasoning, situation awareness and decision making ability should be assessed.
- When evaluating the impact of Inputs on performance consideration should be given to whether they impact on simple tasks and/or complex tasks. In other words the type of military task on which the Input will affect performance.
- Studies should obtain metrics for all three components of the triad of Input, adaptation responses and Outputs. For example, if looking at the impact of encapsulation on performance, metrics used would relate to: thermal measures, physiological (and, if possible, cognitive) adaptations, and observable outputs (task performance).

## 9. Future Directions

As identified in the preceding literature review, modern warfare not only sees military personnel facing “traditional” challenges but also dealing with increased uncertainty and complexity. Personnel are now predominately involved in operations other than war (OOTW); operations increasingly involve asymmetric warfare in which the enemy is no longer obvious and behaves in unpredictable ways to compensate for a lack of technological superiority. Irrespective of the nature of the operation and environment within which it occurs, military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. The importance of the impact of stress on the wellbeing of military personnel is recognised by defence organisations internationally, largely due to performance failures and an increasing incidence of Post Traumatic Stress Disorder. There is an increased focus on stress training and development of strategies to mitigate the influence of stress on performance.

However, there is confusion about the concept of stress and terminology associated with this phenomenon. A core feature of the theories and models reviewed is the notion of Inputs (environmental and/or task demands), Adaptation (responses occurring within a person that allow them to adapt to environmental and task demands), and Outputs (performance as a consequence of the environmental and task demands and any adaptations made).

Our understanding of the impact of stress on performance is still limited. This is largely due to (1) uncertainty with respect to cognitive resources; (2) immaturity of our understanding of mechanisms involved in evaluating the nature of a perceived threat; (3) few studies investigate changes in the environment and cognitive state over time; and (4) our understanding of the impact of Inputs (stressors) on cognitive performance is limited, as is our understanding of the interaction of various Inputs.

Selected Inputs of relevance to the military environment were focused on in the preceding literature review. Further research is needed to gain a better understanding of the impact of these on performance.

This research is particularly important if we want to develop means of mitigating against potentially harmful effects of one or more Inputs. If we can identify appropriate mitigation strategies to optimise soldier performance, such strategies are also likely to improve soldiers’ well-being due to the reduction on overall stress.

The following sections identify what the author regards as key research areas that can potentially enhance our understanding of military performance in extreme environments and thus help identify ways in which we may effectively mitigate against the impact of stressors.

## 9.1 Stress

We have an incomplete understanding of the stress concept and its impact on performance, especially cognition. This is largely due to our limited understanding of:

- the nature and mechanisms of cognitive resources
- appraisal mechanisms and how they can help us better understand cognitive mechanisms related to the stress response
- the effect of environmental and cognitive changes over time and the consequences of these effects for a person's adaptation to stressors
- how stressors interact and the consequence of these interactions on human performance.

Research in this area is largely conducted at establishments such as universities. However, if theories and models developed from pure research are to be applicable to the operational environment then studies need to be conducted in realistic settings in which participants are exposed to operationally relevant stressors. Moreover, the theories and models need to be evaluated to determine their applicability and utility, (e.g., situation awareness, motivation, workload etc.) (Koltko-Rivera & Hancock, 2008). To be truly generalisable to the military operational environment, these theories and models need to be tested in realistic military environments in which personnel are subjected to typical operational stressors, such as thermal extremes and sleep deprivation; thermal extremes and information overload; sleep deprivation and fatigue; fatigue, thermal extremes, and information overload.

Because of their domain knowledge and security clearances, applied defence researchers are ideally placed to evaluate, and further develop, theories and models arising from the university environment that potentially allow us to answer critical questions such as how stress affects performance; the extent to which performance is degraded by stress; whether the effects of stressors are additive or cumulative; and what we can do to alleviate these effects. Increasing our understanding of issues such as this will enhance our ability to develop mitigation strategies so as to improve soldier performance in the field.

## 9.2 Mental Workload

Despite mental workload frequently being cited as an ubiquitous stressor, it is a nebulous concept. We still have much to learn about the mechanisms underlying the allocation of cognitive resources that enable a person to make optimal complex decisions and/or allocate attention in complex environments. The fuzzy nature of the concept, and our limited understanding of how we adapt to workload demands make it difficult to measure mental workload. More research is necessary to fully understand how stress affects information processing, the allocation of mental resources, as well as identifying factors that control allocation and use of mental resources. Moreover, rather than examining mental workload, it may be more fruitful to focus on cognitive overload – that is, whether the demands of the task and other stressors are excessive such that a person no longer has

the necessary cognitive resources available to perform a required task. The term mental fatigue can then be used to refer to the situation in which a person is close to exceeding their cognitive capacity, or has already exceeded it.

Re-defining mental workload in this way (a) allows us to focus on the crucial question as to whether a task, information, environmental factor, equipment etc. imposes an excessive cognitive burden on the soldier; and (b) better enables utilisation of the Process Model of Stress and Performance (where applicable) as a foundation for applied research. Utilisation of this model would highlight the need to investigate both physiological and cognitive changes in response to environmental and/or task demands. As this would also mean research would be focused on resource demand and availability, this would better enable investigation of the manner in which these physiological and cognitive demands and/or adaptations compete for resources. Consideration of general resource capacity would also allow us to develop our theoretical understanding of cognitive capacity, thus refining the Process Model of Stress and Performance. In this way, research into cognitive fatigue would parallel that looking at allostatic load. For example, what are the critical neurochemical balances required for optimal cognitive performance, and how does allostatic load impact on these?

### 9.3 Thermal Extremes

The impact of thermal extremes on cognitive performance is also still unclear. For example, we need a better understanding of: how thermoregulation impacts on cognitive performance; the temperature range for optimal cognitive performance; the duration for which people can maintain optimal performance around thermal extremes; tasks that can be adequately performed beyond these extremes; gender differences in thermoregulation the effects of thermal extremes on cognition; and the extent to which automaticity might mitigate the impact of thermal extremes.

Future research also needs to remove confounds present in the extant literature. For example, conflation of:

- the impact of hyperthermia and exercise on cognition
- effects of atmospheric phenomena and thermal extremes
- the impact of sweat and thermal extremes.

Studies need to be designed so that they remove these confounds and not only enable identification of the impact of individual phenomena on performance but also the way in which various Inputs interact to impact on performance.

Improving our understanding of the impact of thermal extremes on performance will better us to identify appropriate mitigation strategies.

## 9.4 Sleep Deprivation and Fatigue

With respect to sleep research, we still do not fully understand the function of sleep. As identified in the preceding literature review, the effects of sleep deprivation on both psychomotor and cognitive performance are profound. Although Defence organisations utilise sleep management plans there is evidence that these are not always adhered to, due to high operational tempo. Given the high potential for soldiers to compromise their performance efficacy, more research is necessary to determine the optimal sleep/wake cycles for soldiers who by necessity are engaged in SUSOPS or ConOPS. Such research is also needed to enable us to more fully understand the consequences of SUSOPS and ConOPS on cognitive performance. Extant evidence indicates that a large number of cognitive abilities are markedly affected. However, several questions arise. For example:

- How many “incidents” on operations might be avoided if we better understand the impact of sleep deprivation on cognitive processes such as learning and memory?
- To what extent are ergogenic aids (e.g., caffeine, sleeping tablets) masking the long-term effects of sleep deprivation?
- Are we compromising long-term optimal performance for short-term gain?

Fatigue is generally conflated with sleepiness, so our understanding of the impact of fatigue on performance is confounded. The merging of sleepiness and fatigue, their close relationship, and the similarity in their impact on performance means our understanding of fatigue itself is limited. Moreover, if we are unable to clearly delineate sleepiness and fatigue we are unable to identify their respective impact on performance (Balkan & Wesensten, 2011). This makes it difficult to predict the impact of either concept on performance during SUSOPS or ConOPS, and thus limits our ability to develop effective mitigation strategies so as to sustain and optimise performance. The phenomenon of fatigue needs to be better defined and more clearly delineated from sleepiness. A starting point could be to focus on resource capacity, and identify the extent to which soldiers can safely adapt to continuous environmental stressors affecting their physical and cognitive performance without reaching the point of allostatic load.

## 9.5 Resilience

Resilience training is believed to enhance soldiers’ capacity to cope with potentially adverse events and is therefore being incorporated into regular training in Defence organisations world-wide. However, there is a relative dearth of empirical research evaluating the efficacy of this training. Indeed, some recent findings suggest that some forms of resilience training, whereby soldiers are exposed to stressors they may face whilst deployed, may in fact result in decrements in performance in the field on challenging or complex cognitive tasks (see Stanley & Jha, 2009). The United States army is currently undertaking a study to evaluate the efficacy of its resilience training program (see e.g., Lester McBride, Bliese, & Adler, 2011).

Some studies investigating means of increasing soldiers’ resilience have found that mind fitness training might better prepare soldiers for operational stressors, than do techniques

based on stress inoculation, cognitive behavioural therapy and positive psychology. Such training utilises a range of procedures including neurofeedback and has been shown to reduce stress as well as improving attention, situation awareness, mental agility, and emotional control (e.g., Stanley & Jha, 2009; Stanley, Schaldach, Kiyonaga & Jha, 2011). A study is currently underway investigating the usefulness of mind fitness training in a group of 320 US Marine Corps personnel. It is being conducted by Dr Chris Johnson of the Naval Health Research Centre in collaboration with personnel from universities and the Mind Fitness Training Institute.

There are also suggestions that the brain circuitry and levels of one or more neurochemicals (e.g., Neuropeptide Y) may be inherently different in military personnel who naturally display high resilience (e.g., Special Forces) (see e.g., Lester, McBride, Bliese, & Adler, 2011; Reichm, Zutra & Hall, 2010; Vythilingam et al., 2009).

We currently do not fully understand the manner in which resilience training promotes adaptive mechanisms within the human system so as to prevent allostatic load. However, there is converging evidence that Neuropeptide Y plays a role in the stress response, and may mitigate against development of Post Traumatic Stress Disorder. (e.g., Cohen, Liu, Kozlovsky, Kaplan, Zohar & Mathe, 2012).

Training of military personnel takes considerable time and effort. The selection and training of Special Forces personnel involves even more time and effort. Techniques allowing the ADF to identify people who inherently have strong resilience to adverse situations would enable them to cull their applicants for the Special Forces at an earlier stage in the selection process and thus reduce their failure rate.

Recent research has also indicted that some people are naturally more resilient to sleep deprivation than are others (Van Dongen & Belenky, 2009). The ability to identify such people within the military population, would also help in pre-selection of personnel for situations where they need to be awake and alert for extended periods of time. For example, identification of personnel more resilient to sleep deprivation as well as having an innate resilience to stressful environments would more rapidly allow short-listing of personnel potentially suitable for the Special Forces.

## **9.6 Adaptive Automation**

Although our ability to develop strategies to mitigate the impact of stress on performance is limited to our extant understanding of mechanisms involved, this does not prevent research being undertaken in this area. A key area here is that of adaptive automation, which is also related to the growing research in augmented cognition. One of the aims of the latter is to design technological aids that reduce the burden on the soldier by behaving in a biologically plausible fashion and thus enhance and/or complement the soldier's capabilities. As stated in the preceding literature review, a central feature of adaptive automation is the appropriate allocation of tasks and/or task components between technology and the human to maximise performance outcomes. Dependent on the nature of the adaptive automation, reallocation of effort between the human and technology may

be initiated by either entity. Research on unmanned vehicles (air, land, sea) and robotics can be included in the area of adaptive automation as the aspiration of these is to minimise soldiers' exposure to danger, as well as to reduce the burden on soldiers during operations.

Another goal of augmented cognition is the monitoring of soldiers' performance in the field. The purpose of this is dual-fold: (a) to monitor soldier health so interventions can occur to minimise impacts on physical and mental health; and (b) to identify when a soldier's performance is about to decline so mitigation strategies can be employed. Although rapid advances have been made with respect to appropriate metrics and technology for monitoring of soldier performance, research is still necessary to identify the most appropriate and relatively unobtrusive technologies. Research is also needed to identify suitable algorithms to identify when a soldier is becoming overwhelmed by environmental and task demands.

## 9.7 Metrics

The appropriate tasks and measures will depend on the research question being addressed. Nonetheless, wherever possible, tasks should be readily identifiable as being of relevance to the military. Researchers in organisations such as DSTO, NATO, ARL/HRED, Walter Reid Army Institute of Research, the U.S. Army Research Institute of Environmental Medicine have already identified some appropriate tasks. For example, vigilance tasks map onto sentry duty; target acquisition and detection tasks map onto marksmanship, as does reaction time and accuracy; spatial navigation tasks relate well to map-reading; working memory and/or decision making task relate to simple and complex decision making. It is essential that the tasks used simulate the operational environment and nothing is present that inadvertently provides support that will be absent during operations. Stressors used need to elicit measurable changes in performance, subjective feelings of discomfort or danger, and physiological processes (Berkun, 2012).

With respect to measures, these should be appropriate to the research question and the experimental tasks used. However, to more fully understand the impact of Inputs on performance, subjective, objective and performance measures need to be collected. Subjective measures may include self-evaluation of stress levels, workload, relevant personality factors, demographics etc. Objective measures may include eye metrics (e.g., blink rate, pupil size, gaze etc.), brain activity (e.g., EEG amplitude and frequency, brain blood flow), heart metrics (e.g., heart rate, heart rate variability), respiration rate, muscle activity, neuroendocrine levels (e.g., cortisol, amylase, noradrenaline, neuropeptide Y, adrenaline) etc. When selecting Output measures, researchers should consider whether the task requires psychomotor and/or cognitive processes. In some cases it would be advantageous to include psychological measures (e.g., learning effects, divested tasks), as these may impact on performance and/or provide insight into whether a person is engaging in task/performance tradeoffs. It is also important to assess potential moderating variables so the impact of these on the relationship between Input and Output

can be controlled for. This will require using metrics evaluating factors such as skill levels, self-efficacy, personality, confidence etc.

Further consideration of the nature of these processes will allow the researcher to select appropriate performance metrics such as reaction time, error rate, accuracy, hits and misses, time taken, memory performance, engagement/disengagement of attention, situation awareness, decision making quality etc.

To enable development of a more realistic picture of the impact of extreme environments on performance, two or more relevant stressors should be manipulated to expose participants to different degrees of the Input (e.g., heat, cold, vibration, task demands, temporal demands). As well as measuring performance and changes within a person, researchers should also provide ambient metrics where applicable.

Physiological responses not only provide an objective measure of cognitive and physical demands; they can also give insight into the adaptation of the human system to stressors. For example, changes over time in neuroendocrine levels, heart rate variables, brain activity etc. that reflect processes involved in allostasis and onset of allostatic load.

To enhance generalisation to the military environment and transfer of findings across different research areas, it is recommended that:

- Military relevant tasks are used in any research related to investigation of the impact of stress on performance. This maximises military “buy-in”.
- Subjective, objective and performance measures are used in all studies investigating the impact of stress on performance. Objective measures should also include one or more metrics assessing participants’ stress levels (e.g., cortisol).
- Ambient measures are included as appropriate.
- Potential moderating variables are identified and measured.
- metrics and technology are developed that enable effective and relatively unobtrusive monitoring of soldier performance in the field.

## 9.8 Operational Neuroscience

A main aim of the field of neuroscience is to be able to understand how the nervous system underpins behaviour. Cognitive neuroscience is a branch of neuroscience focusing on cognition. The last decade has seen major advances with respect to technologies used, as well as our understanding of the structure and function of the human brain. Findings from the neuroscience community have been used as the foundation for such programs as the United States’ Augmented Cognition and Improving Soldier Performance in the field. The ultimate objective of such programs is to devise means to monitor soldier performance and improve it, identify when the soldier is cognitively or behaviourally at risk, and devise technologies that augment soldier performance.

The area of operational neuroscience grew out of recognition that, despite its promise, neuroscience was not well utilised outside the clinical setting. However, unlike neuroergonomics that focuses more on the interaction between humans and artifacts or technology, the focus of operational neuroscience is the operator functional state and how that relates to operational environments. Operational neuroscience moves beyond a focus on humans' interaction with artifacts and technology to encompass consideration of all factors impacting on the operator functional state. Specifically, it uses principles and findings of neuroscience to enhance training, system design, soldier-system integration, monitoring of the operator state, as well as the soldier's physiological and psychological state and their skill levels (Kruse, 2007). Thus, the research scope of operational neuroscience is broader than that of neuroergonomics. It not only facilitates an understanding of humans' interactions with their environment and technology design, but also provides insight into factors such as their functional state, the relationship between this functional state and adaptive automation technologies, training enhancements etc. Internationally, defence organisations are conducting research to devise means of monitoring the operator state, so the commander in the field can identify personnel who are better equipped at a particular point in time to perform specific tasks. Further objectives of such research include identification of personnel who maybe more resilient to stress as well as the identification in the field of personnel at risk of developing illnesses such as Post Traumatic Stress Disorder.

To better understand soldier performance in extreme environments, it is recommended that findings and methods from operational neuroscience are integrated with those from other areas, such as training, social sciences, operations analysis, soldier-system integration, team dynamics etc. This will provide a richer understanding of the impact of stressors on performance and more readily allow identification of where mitigation is necessary and the nature of this mitigation.

## **10. Overall Summary of the Impact of Inputs on Performance, and Questions Raised**

This paper has provided an overview of theories, models and research relevant to our understanding of how people perform under stress – that is, when faced with environmental and/or task demands that potentially disrupt their homeostatic state. The Process Model of Human Performance (Hancock et al., 2001), which is underpinned by the Maximum Adaptability Model (Hancock & Warm, 1989), is proposed as the most useful theory and model on which to base research. It considers the role of Inputs on performance (outputs); the capacity of the human system to meet the demands of the Inputs; and the Adaptation processes that occur in response to the Inputs. Hancock et al.'s (2001) model also considers possible interactions and/or cumulative effects of: (a) different types of Inputs; (b) physiological and cognitive responses to Inputs; and (c) behavioural and physiological adaptations to the Input demands. These considerations, together with recognition of the importance of the role that capacity plays in Adaptation, make this model particularly useful for predicting the impact of one or more Inputs on performance,

Adaptation, and capacity. The model is based on the extended-U curve of Hancock and Warm (1989) which has been shown to explain several research findings (see e.g., Cosenzo, Fatkin & Patton, 2007; Oron-Gilad & Hancock, 2008). It identifies how people can perform at an acceptable level for a certain period of time, after which performance might deteriorate markedly, reflective of allostatic load.

Some factors that potentially disrupt performance are relatively well researched (e.g., sleep deprivation, mental workload, noise). However, there is still much we do not know about these factors. This overview has raised many questions and areas for consideration. For example:

- Noise
  - How do physiological and psychological adaptations to noise interact?
  - What is the impact of noise on vigilance tasks?
- Thermal Extremes
  - There are many confounds with respect to the impact of thermal extremes on performance. For example, relatively little research has collected physiological and cognitive data. Such research would enable a better understanding of both physiological and cognitive responses to thermal extremes, the adaptation processes involved, and how the physiological and cognitive responses interact.
  - Much of the research on thermal extremes has used exercise as a means of increasing temperature. However, as exercise can facilitate performance, exercise may have masked the true impact of heat on performance.
  - How do thermal extremes (or noise, vibration, mental workload etc) interact with sleep deprivation?
- Sleep Deprivation/Fatigue
  - With respect to sleep research, we still do not fully understand the function of sleep. In what way are we disrupting the beneficial purposes of sleep by using pharmacological aids to enable soldiers to maintain alertness and performance for extended periods?
  - Are performance deficits seen during vigilance tasks the result of fatigue or boredom? If the latter, this means a person may be under aroused, which disrupts performance in a similar way as does over arousal. However, if vigilance decrements are due to boredom, merely providing some form of stimulation might increase arousal and enhance performance; whereas, if anything, further stimulation is likely to result in hyper arousal and further degrade vigilance performance.

Other considerations have also been raised, such as the role of resilience training, the relatively new areas of adaptive automation and augmented cognition, and the potential cumulative effects of physical and/or cognitive inputs on soldiers' performance. Further, and importantly, laboratory findings have rarely generalised to the operational environment. Therefore, with respect to the military, it is important that any evaluation of

the impact of potential stressors on soldier performance be conducted in an environment comparable to that in which they will operate. The same applies to evaluation of new equipment and/or technology. We need to understand if the technology and/or equipment functions effectively in its own right. However, if we have not assessed whether it will function in the operational environment in which it will be used, that soldiers can use the equipment in that environment, and that it does not increase the burden on them, then we run the risk of increasing their already high operational demands. As the Process Model of Stress and Performance identifies, it is also important to measure physiological and cognitive responses when evaluating potential stressors – or new equipment – so we can fully understand the impact on a person.

In order to effectively evaluate the impact of Inputs on performance, we need to be clear as to the research question of interest, and ensure the methodology is appropriate to address this question. Selection of appropriate methodology involves use of appropriate tasks, identification and/or measurement of relevant levels of the Input of interest, consideration of possible Adaptation responses, consideration of moderation factors, and selection of appropriate metrics for evaluating performance (the Output). Ideally, the tasks and metrics used should be relevant to the military environment so the soldier can readily identify with them. They should also be tasks and metrics utilised by other researchers interested in the same or similar research questions. This will better enable replication and cross-validation of research findings, which more rapidly allow us to gain a better appreciation of the impact of stress on military performance.

All of the Inputs addressed in this paper can impact soldier performance. There are many unknowns with respect to these stressors, and new technology is increasingly placing demands on the soldier. As identified, stressors seldom occur in isolation and there is a paucity of research with respect to their combined effects. If we are to improve soldier performance in the field, it is important to conduct research to give us a better understanding of the impact of Inputs on Outputs, as well as the Adaptation processes involved. Although soldier mental health is not the focus of this report, identifying means of mitigating the effects of Inputs on Outputs, and instigating appropriate mitigation strategies, is likely to reduce the mental health impacts as well as improving performance.

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19. ABSTRACT Military personnel are exposed to a range of stressors that potentially impact on their performance and wellbeing. If we are to gain a better understanding of the impact of the operational environment and operational demands on soldier performance we need to understand the way in which these impact on the soldier. This paper focuses on the impact of stress on military performance. Some key theories and models that describe the stress concept are briefly reviewed. A core feature of the majority of these is the notion of Inputs (environmental demands), Adaptation (responses occurring within a person that enable them to adapt to environmental demands), and Outputs (performance as a consequence of the environmental demands and any adaptations made). This paper identifies confusion surrounding the concept of stress and terminology such as stressor. An overview of selected Inputs is followed by an oversight of the nature of Adaptation. Research related to Outputs is summarised and a brief overview provided of methodological issues. The paper identifies that there are many unknowns with respect to the impact of Inputs on Outputs, and also the Adaptation responses. To better identify means of optimising soldier performance and mitigate against potential negative effects to Inputs, more research is needed. It is particularly important to conduct field studies that consider the interactions of two or more stressors (Inputs).					